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ALL ABOUT SPACE

ISSUE 134
SEPTEMBER 2022

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CONSTELLATIONS ARE CLOSE TOGETHER

DO BLACK HOLES SUCK?

IS THERE GRAVITY IN SPACE?

20 UNIVERSE MYTHS BUSTED

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WELCOME

ISSUE 134

Have you ever seen a really amazing fact about the universe and thought that it sounded too mind-boggling to be true? I have! While the cosmos really is an incredible place, with many strange goings on that seem to defy expectations, there can often be misinformation about – myths that have continued to exist from generation to generation. This issue, we've uncovered the top 20 myths about space, so the next time you're confronted with a 'fact', you can turn to page 14 to reveal whether it's really fact or fiction.

Elsewhere in the issue, we get up close and personal with the gigantic structures known as galaxies and how to build one. This issue, you'll discover that there are a collection that seem to swirl peacefully in the vastness of universe, while others are extremely energetic, blasting jets of radiation from the insatiable black holes at their centres. Your old favourites are all here, from Ask Space to our night-sky guide, packed with the very best observing advice as we head into autumn. With that in mind, I'll leave you to prepare your telescopes, binoculars, eyepieces and other observing kit. Let me know what you discover in the coming weeks!

GEMMA LAVENDER
Content Director

ALL ABOUT SPACE
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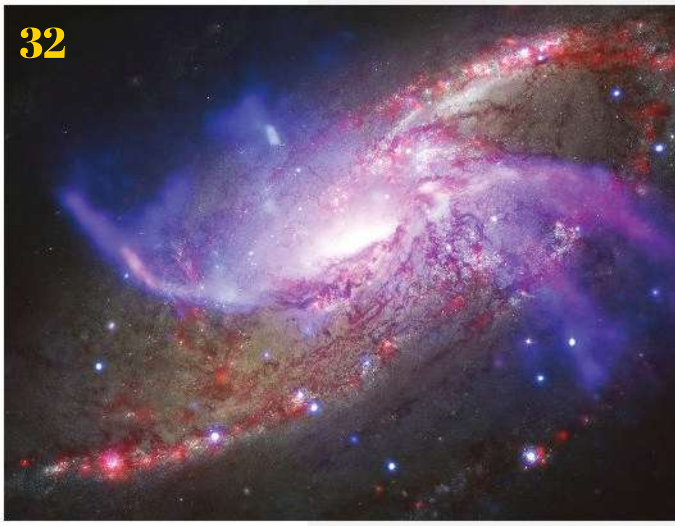

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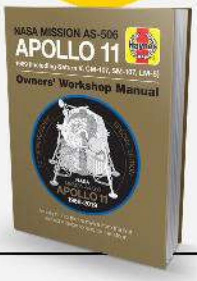


9 August 2022

Clash of the galaxies

Astronomers at the Gemini North telescope in Hawaii have released a stunning image that shows two spiral galaxies in the process of colliding and merging. The clashing galaxies NGC 4568 and NGC 4567 – also known as the Butterfly Galaxies due to the dual-lobed shape their interaction causes – are located 60 million light years away from Earth in the Virgo Cluster and will form a brand-new elliptical galaxy in around 500 million years.

The new image gives scientists a sneak preview of what will happen in around 5 billion years when our galaxy, the Milky Way, collides with its closest large neighbour, the Andromeda Galaxy. That clash will give each galaxy a major makeover, as well as possibly flinging the Sun and the Solar System into a different region of the resulting galaxy.

The image depicts the early stages of a galactic merger – one of the most spectacular events in the universe – and shows the two galaxies locked together by their mutual gravitational field. The respective centres of NGC 4568 and NGC 4567 are still around 20,000 light years apart, about three-quarters the distance between Earth and the heart of our home galaxy.

© NOIRLab

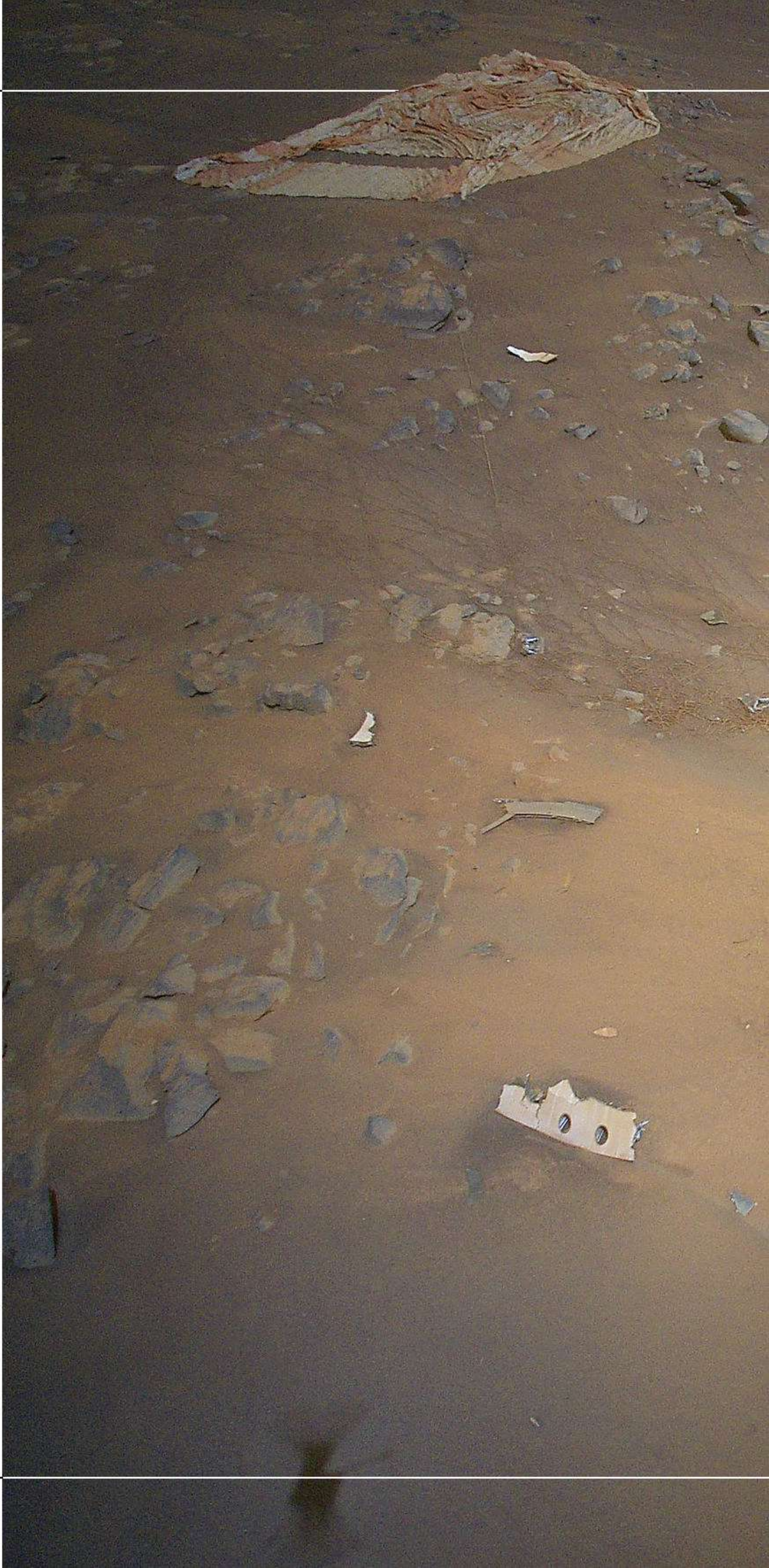
6 August 2022

Perseverance photographs its landing debris

On Mars, there's a unique kind of tumbleweed rolling across the Martian plains. These tumbleweeds aren't plants - they're pieces of debris from the entry, descent and landing (EDL) hardware from NASA's Perseverance rover. The rover has been coming across many of these remnants, photographing them so that engineers can study them.

During its landing on 18 February 2021, a number of hardware elements slowed the spacecraft's speed from 20,000 kilometres (12,500 miles) per hour when it first entered the Martian atmosphere to essentially zero when it was gently placed on the surface by a sky crane – and that all happened in seven minutes. Once their jobs were complete, EDL hardware like the parachute, backshell, heat shield and the sky crane were all jettisoned from Perseverance, crashing into Mars some distance away from the rover so as not to damage it.

Over the past year and a half, the Perseverance team has spotted and catalogued around half a dozen pieces of suspected EDL debris. The first piece was discovered on 16 April 2022 when an unusually bright object was spotted in one of Perseverance's panoramic Mastcam-Z photos. "No one knew what it was at the time, but perhaps the rover would take a closer look as it climbed up onto the delta in the coming weeks," said NASA officials after the discovery.



© NASA/JPL-Caltech

1 August 2022

Hubble's seeing stars

The James Webb Space Telescope's predecessor, the trusty Hubble Space Telescope, is showing us why it shouldn't be forgotten now its successor is beaming back images. NASA and the European Space Agency (ESA), who co-manage Hubble, have just released a new spectacular image of globular cluster NGC 6638, a star cluster in the constellation of Sagittarius. The image was created from observations by Hubble's Wide Field Camera 3 and the Advanced Camera for Surveys.

Prior to Hubble, it was nearly impossible to discern the individual stars in a globular cluster – a dense collection of ancient stars numbering in the tens of thousands to millions. Because ground-based telescopes have to peer through Earth's atmosphere in order to see stars, their view can become distorted. That's less of an issue for Hubble, which orbits Earth at (547 kilometres (340 miles) above the surface. By comparison, Webb is about 1.5 million kilometres (1 million miles) from Earth – though it primarily operates in the infrared spectrum, while Hubble operates in the visible-light spectrum. That means Hubble is technically located within the atmosphere, which extends out for 10,000 kilometres (6,200 miles). With less of the atmosphere to peer through, Hubble has been instrumental in globular cluster research, and it continues to make new discoveries regularly.

© ESA/Hubble & NASA

Colliding black holes could clock the universe's expansion rate

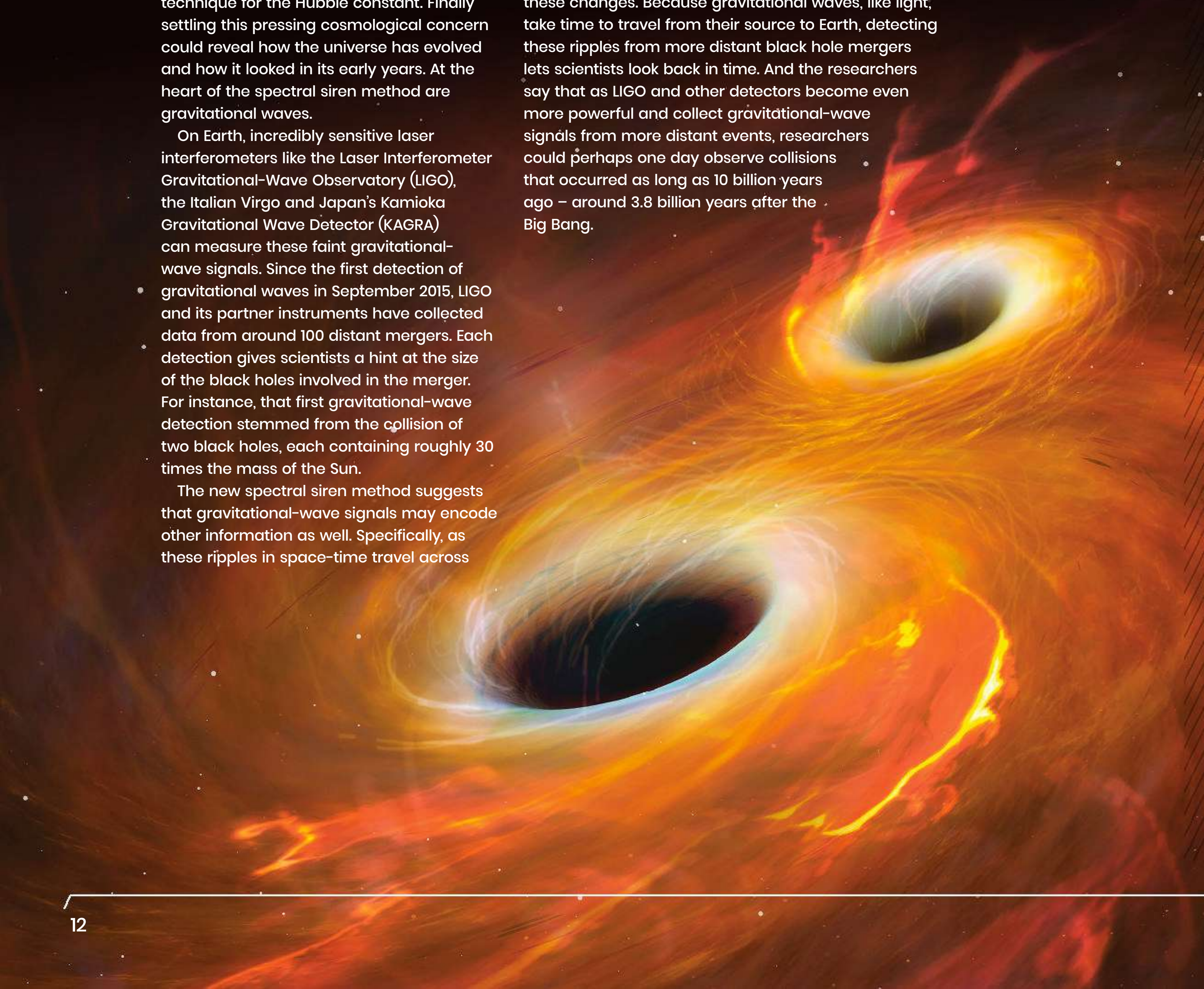
Reported by Robert Lea

Scientists may have found a way of using the collisions of black holes to measure the rate at which the universe is expanding. The violent mergers of black holes launch ripples in space-time called gravitational waves, and a new technique measures changes in these signals that occur as they experience the universe's expansion. Scientists hope to use cosmic collisions between tight binary black hole pairings as what the team term 'spectral sirens' to provide an alternative measurement technique for the Hubble constant. Finally settling this pressing cosmological concern could reveal how the universe has evolved and how it looked in its early years. At the heart of the spectral siren method are gravitational waves.

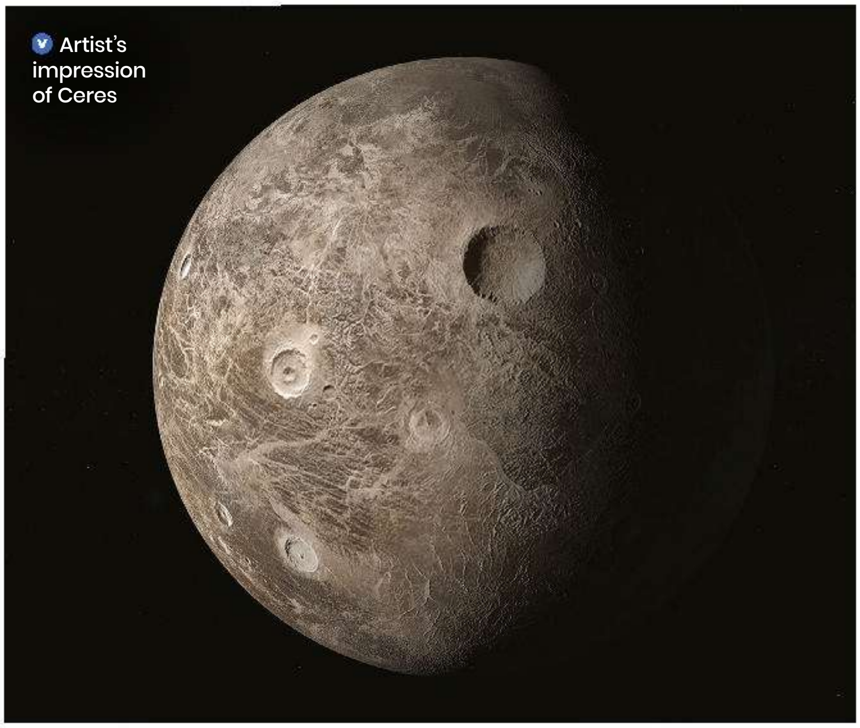
On Earth, incredibly sensitive laser interferometers like the Laser Interferometer Gravitational-Wave Observatory (LIGO), the Italian Virgo and Japan's Kamioka Gravitational Wave Detector (KAGRA) can measure these faint gravitational-wave signals. Since the first detection of gravitational waves in September 2015, LIGO and its partner instruments have collected data from around 100 distant mergers. Each detection gives scientists a hint at the size of the black holes involved in the merger. For instance, that first gravitational-wave detection stemmed from the collision of two black holes, each containing roughly 30 times the mass of the Sun.

The new spectral siren method suggests that gravitational-wave signals may encode other information as well. Specifically, as these ripples in space-time travel across tremendous distances and over long timescales to reach Earth, the properties of their signals are changed by the expansion of the universe. "For example, if you took a black hole and put it earlier in the universe, the signal would change and it would look like a bigger black hole than it really is," University of Chicago astrophysicist Daniel Holz said.

In order to unlock information about the expansion rate of the universe coded in gravitational-wave data, scientists will need to know how the signal has changed since it was launched through space. Holz and his colleagues think that a newly discovered population of local black holes could be used as a tool to assess these changes. Because gravitational waves, like light, take time to travel from their source to Earth, detecting these ripples from more distant black hole mergers lets scientists look back in time. And the researchers say that as LIGO and other detectors become even more powerful and collect gravitational-wave signals from more distant events, researchers could perhaps one day observe collisions that occurred as long as 10 billion years ago – around 3.8 billion years after the Big Bang.



Black holes send out gravitational waves when they interact with one another



Artist's impression of Ceres

Radioactive heat in Ceres drove the dwarf planet's fractured geology

Reported by Charles Q. Choi

Radioactive matter within the dwarf planet Ceres may help drive geological activity there. With a diameter of about 940 kilometres (585 miles), Ceres is by far the largest member of the asteroid belt. In 2015 NASA's Dawn spacecraft became the first orbiter around Ceres. The probe revealed the dwarf planet was covered in features resembling those from tectonic activity, such as a continent-like plateau and criss-crossing fractures. Now research suggests heat from the decay of radioactive elements within Ceres might help keep it geologically active.

Scientists analysed the interior of Ceres using computer models previously applied to bigger planets. Results suggested that because Ceres is relatively small, it lacked a gravitational pull strong enough to result in powerful collisions to heat it up. As such, Ceres may have started off cold. Over time, the decay of radioactive elements such as uranium and thorium within Ceres may have heated up the dwarf planet until its interior became unstable. "What I would see in the model is, all of a sudden, one part of the interior would start heating up and would be moving upwards and then the other part would be moving downwards," study lead author Scott King, a geoscientist at Virginia Tech, said.

Such instability might explain some of the surface features the Dawn mission saw on Ceres. For example, its large plateau formed on just one side of the dwarf planet, with nothing similar on the other side, and its criss-crossing fractures were clustered around the plateau in a single location. The concentration of these features in one hemisphere suggested instability concentrated on just one side of the asteroid. "It turned out that you could show in the model that where one hemisphere had this instability that was rising up, it would cause extension at the surface, and it was consistent with these patterns of fractures," King said. These findings suggest Ceres did not follow a planet's typical pattern of hot first and cool second, but a pattern of cool, hot and then cool again.

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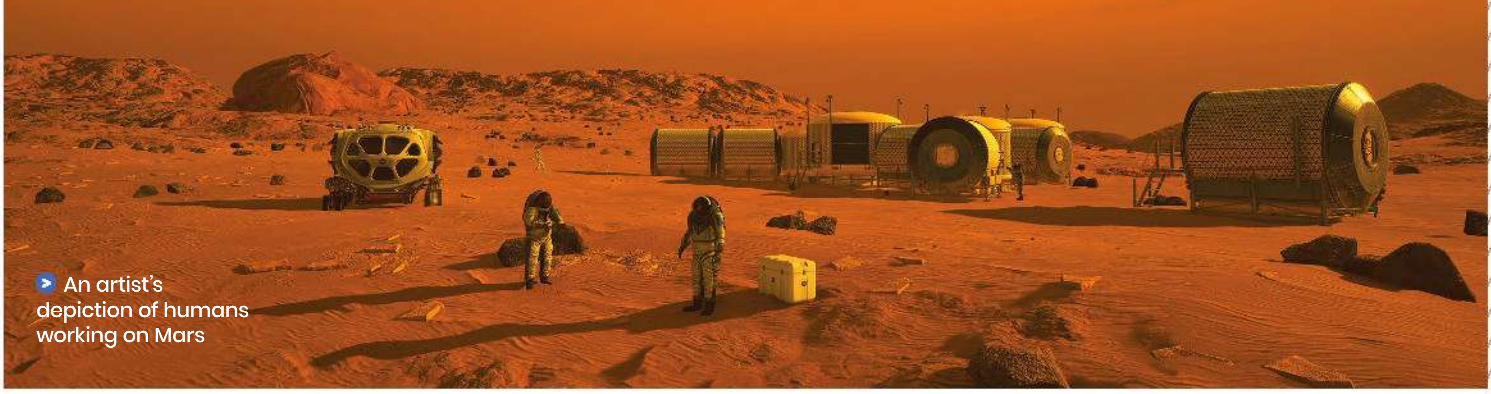
Mars explorers could harvest oxygen from the atmosphere using plasma

Reported by Andrew Jones

Oxygen is vital for life support, producing fuels and supporting agriculture. Being able to harvest it on Mars will be vital for future crewed missions. But producing oxygen on the Red Planet is challenging. Although there's plenty of the element in the Martian atmosphere, it's locked up in carbon dioxide molecules, which are very difficult to break. And any oxygen produced from this then needs to be separated from a gas mixture that also contains, among other things, carbon dioxide and carbon monoxide.

Plasma contains free charged particles, including electrons which are light and easily accelerated to very high energies with electric fields. "When bullet-like electrons collide with a carbon dioxide molecule, they can directly decompose it or transfer energy to make it vibrate," said Vasco Guerra, a physicist at the University of Lisbon in Portugal. "This energy can be channelled, to a large extent, into carbon dioxide decomposition." Researchers hope that the technique could deliver high rates of oxygen production with relatively lightweight instrumentation – always a factor when launching from Earth.

"Together with our colleagues in France and the Netherlands, we experimentally demonstrated the validity of these theories," Guerra said. "Moreover, the heat generated in the plasma is also beneficial for the separation of oxygen." The approach could complement NASA's Mars Oxygen In-Situ Resource Utilization Experiment (MOXIE), which extracts carbon dioxide from the atmosphere and turns it into oxygen and carbon monoxide.



An artist's depiction of humans working on Mars

Underwater snow on Earth could offer insight into Europa's icy crust

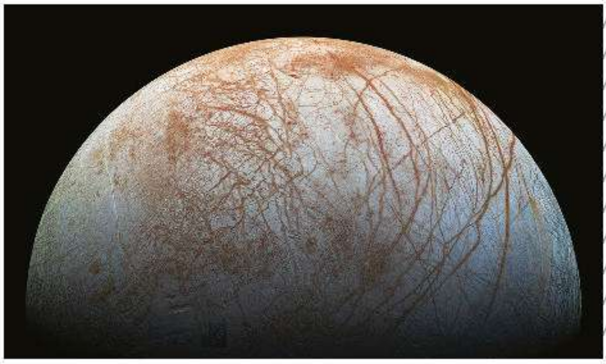
Reported by Andrew Jones

Studying unusual processes of how ice accumulates below ice shelves here on Earth could hold lessons for the exploration and habitability of Jupiter's moon Europa. Researchers studied two types of underwater snow found on Earth as an analogue for understanding how Europa's shell thickens from below. Frazil ice forms in supercooled water columns and floats upwards to accrete onto the bottom of ice shelves, while ice grows directly from under the ice shelf. The researchers determined that ice formed by these processes retains just a fraction of the salt from the water from which it formed. Frazil ice retains just 0.1 per cent of the ocean's salinity and could be common on Europa, suggesting that Europa's ice shell could be orders of magnitude purer than previous estimates.

"When we're exploring Europa, we're interested in the salinity and composition of the ocean because that's one of the things that will govern its potential habitability or even the type of life that might live there," study lead author Natalie Wolfenbarger of the University of Texas Institute for Geophysics, said.

The new information may be of great value in informing upcoming exploration of Europa. NASA's Europa Clipper mission is expected to launch in 2024 and arrive at the icy world in 2030, and the level of salt trapped in the ice can affect how deep the radar on the spacecraft will be able to see into the ice shell and what it can see. Getting a good idea about the crust's composition before arrival will help scientists make sense of the data after the spacecraft gets to work. Previous studies suggest the temperature, pressure and salinity of Europa's ocean nearest to the icy crust is similar to that found beneath an ice shelf in Antarctica.

An image of Europa captured by NASA's Galileo probe



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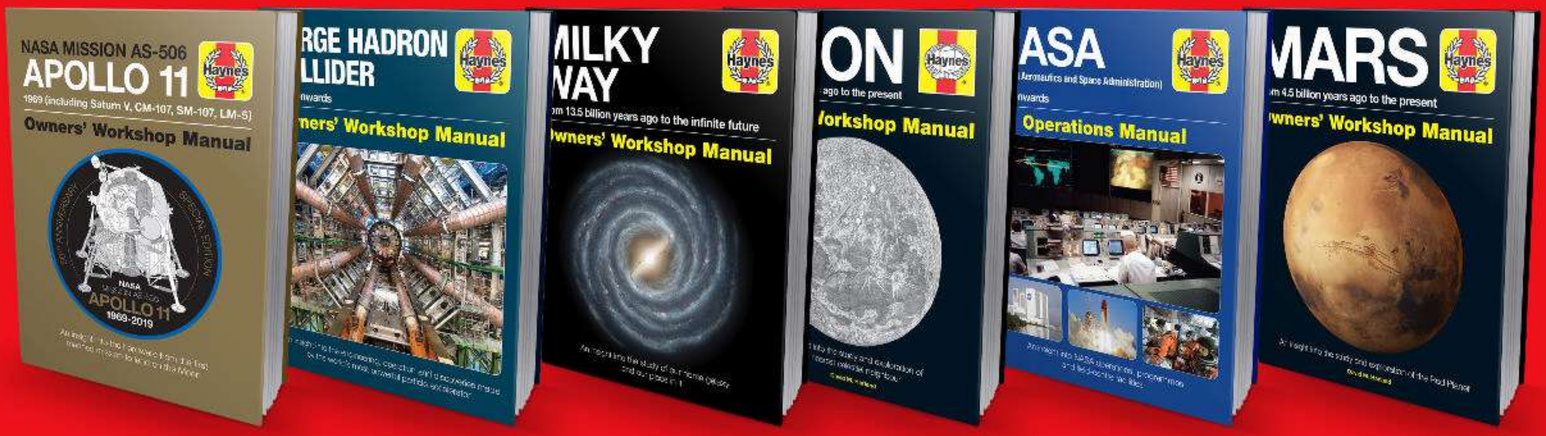
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20 UNIVERSE MYTHS BUSTED

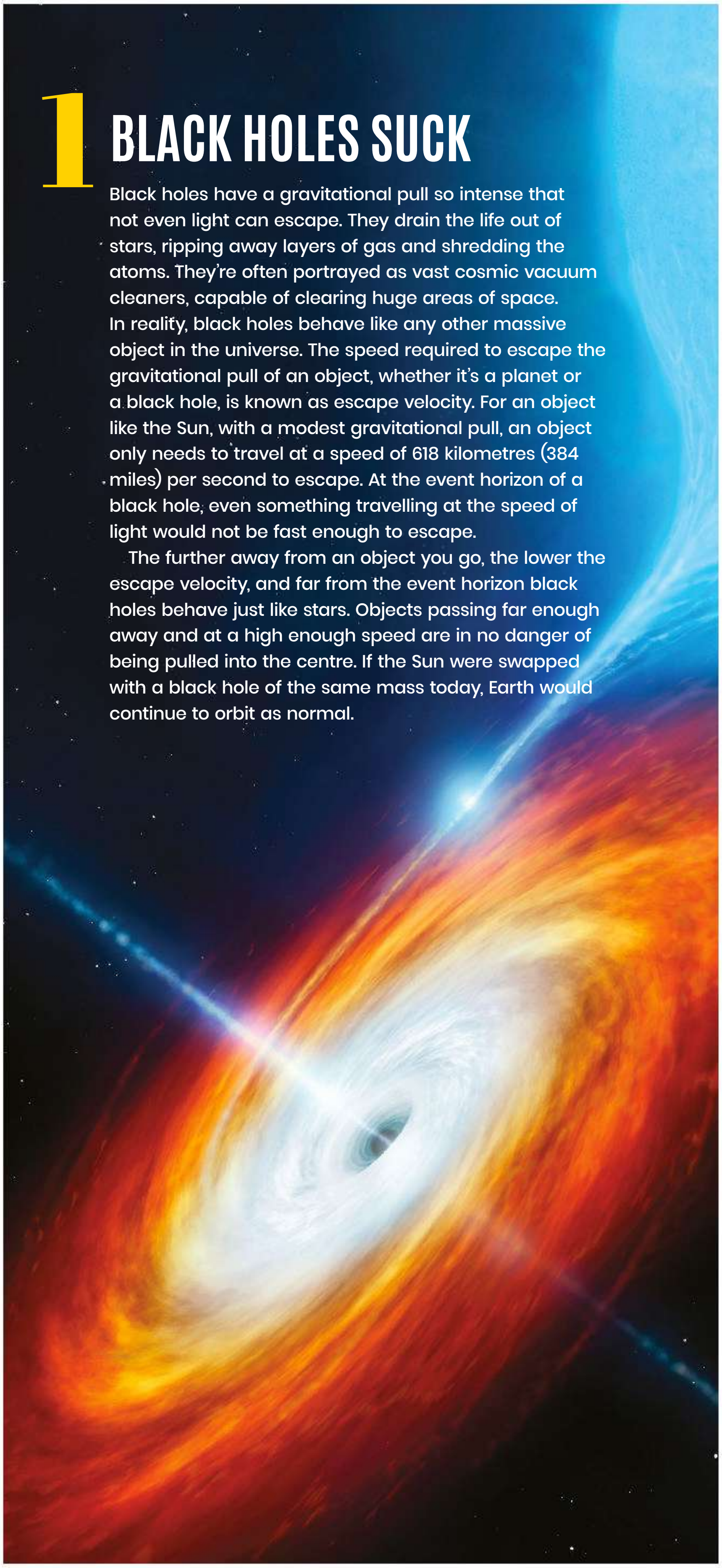
Think you know all about space? Here are 20 myths about the universe that need debunking

Written by Laura Mears

Our understanding of the workings of the universe is better than it has ever been, but there are still a number of misconceptions that manage to fool many of us. Some of the following might sound plausible, but barely any of it is true: the Sun is a burning orb of yellow fire and the temperature is higher during the summer months because we orbit closer than we do in winter. Mercury is the closest planet to our star and must therefore be the hottest.

The lunar phases are caused by the shadow of Earth and at night we can only see one side of the Moon, so the other must be in perpetual darkness. The stars form patterns with their close neighbours and are grouped into local constellations. The twinkling light that they produce travels to Earth in a straight line, unaffected by the pull of gravity. Comets race past with their tails pointing back towards the direction that they came from, and as meteorites tumble through the atmosphere, they heat up so much that it's not safe to pick them up from the ground.

In space, astronauts experience zero gravity and the only human-made object they can see is the Great Wall of China. Friction on re-entry heats their spacecraft to thousands of degrees, and if the astronauts were unfortunate enough to have a collision in space, it would make an audible bang. Any astronaut exposed to the vacuum of space without a spacesuit would explode due to a pressure imbalance. Saturn is the only planet with rings, but in order to reach it you have to travel through the asteroid belt, which is so packed with rocks that it is like a minefield. And watch out for black holes, because they'll suck you straight in.



1 BLACK HOLES SUCK

Black holes have a gravitational pull so intense that not even light can escape. They drain the life out of stars, ripping away layers of gas and shredding the atoms. They're often portrayed as vast cosmic vacuum cleaners, capable of clearing huge areas of space. In reality, black holes behave like any other massive object in the universe. The speed required to escape the gravitational pull of an object, whether it's a planet or a black hole, is known as escape velocity. For an object like the Sun, with a modest gravitational pull, an object only needs to travel at a speed of 618 kilometres (384 miles) per second to escape. At the event horizon of a black hole, even something travelling at the speed of light would not be fast enough to escape.

The further away from an object you go, the lower the escape velocity, and far from the event horizon black holes behave just like stars. Objects passing far enough away and at a high enough speed are in no danger of being pulled into the centre. If the Sun were swapped with a black hole of the same mass today, Earth would continue to orbit as normal.

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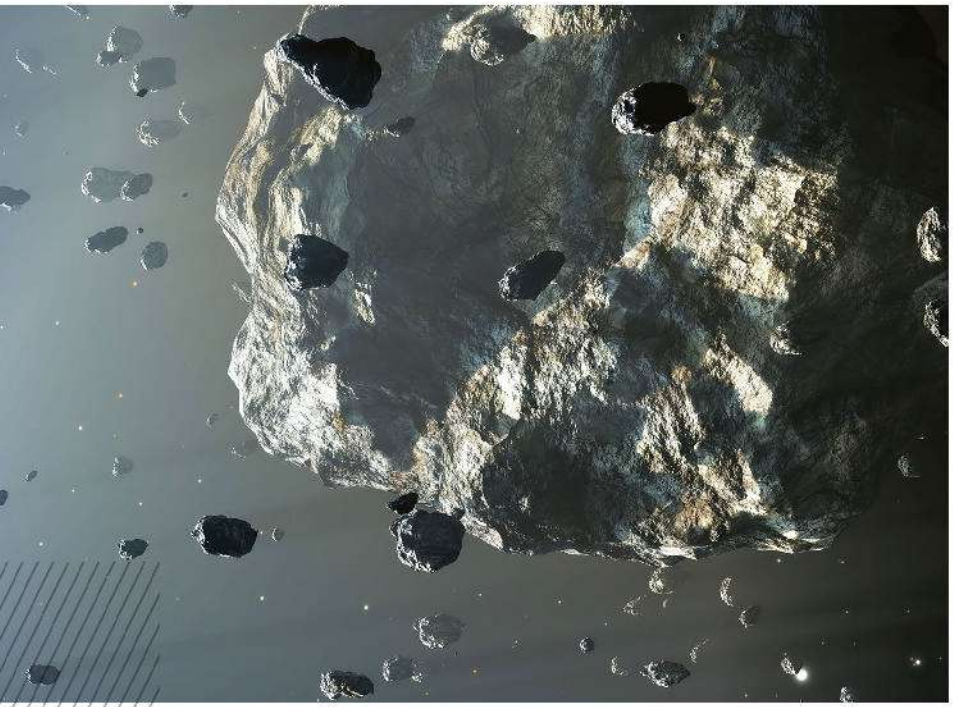


2 THE ASTEROID BELT IS VERY HAZARDOUS

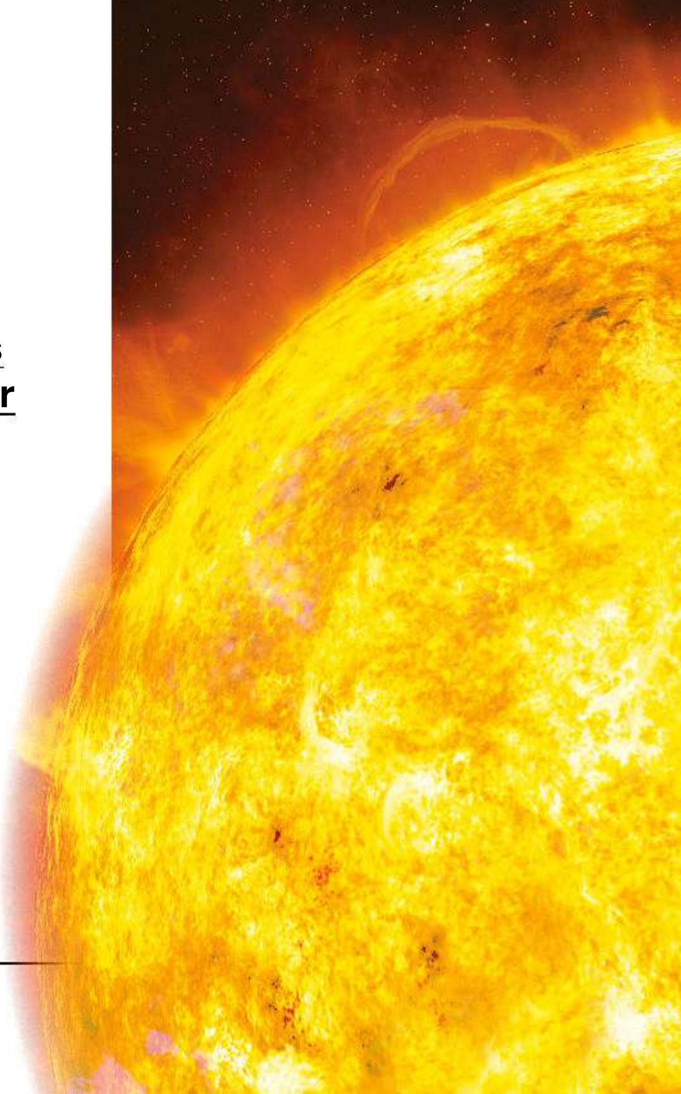
There's no doubt that there is a lot of rock in the area of our Solar System that's known as the asteroid belt. Sitting between Mars and Jupiter, this band of fragments contains over 3,000 minor planets and more than 750,000 separate asteroids measuring more than 1,000 metres (3,280 feet) across. The larger asteroids sometimes collide, spraying smaller fragments into the belt – according to myth, endangering any spacecraft that dares to weave its way through. This myth has been fuelled by science fiction. When Han Solo takes the Millennium Falcon into an asteroid field in *Star Wars: The Empire Strikes Back*, C-3PO warns: "Sir, the possibility of successfully navigating an asteroid field is approximately 3,720 to one". If the Hoth asteroid field is anything like our own, he couldn't have been more wrong.

In the 1970s, NASA's Pioneer 10 became the first spacecraft to navigate its way through the asteroid belt. Only a layer of aluminium honeycomb protected the spacecraft, but despite the apparent danger, it made it's way through with no trouble. Not because of careful evasion, but because the distance between asteroids is huge. On average, there's a distance of around 970,000 kilometres (600,000 miles) between the asteroids, which is more than twice the distance from Earth to the Moon. When compared to the crowded space imagined in the movies, the asteroid belt is actually relatively empty. A much bigger danger in the asteroid belt is the dust-sized particles that form when asteroids collide. These tiny grains could definitely cause damage to spacecraft, but evading rocks the size of a grain of sand doesn't make for very good television.

> **"This band of fragments contains over 3,000 minor planets"**

3 THE SUN IS YELLOW

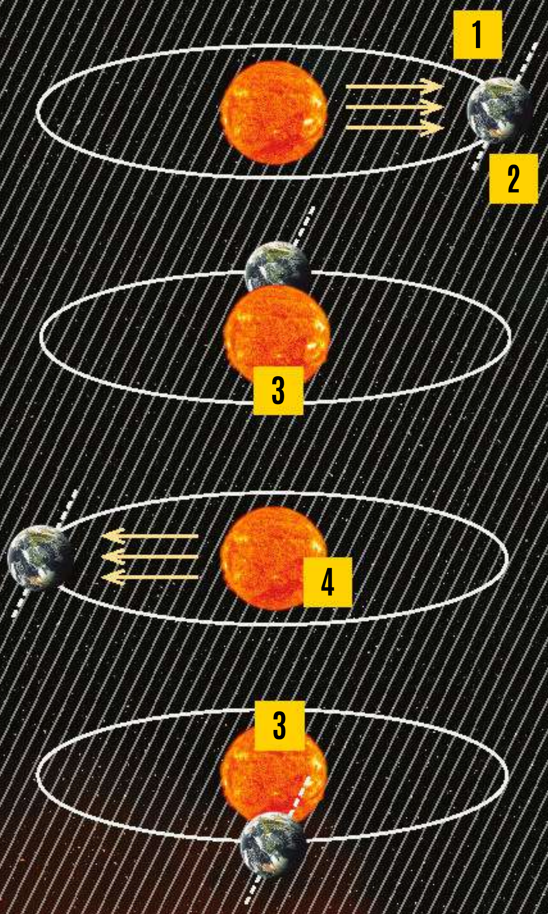
Though you should never look directly at the Sun, photographs reveal a yellowish hue. The Sun produces all wavelengths of visible light, and therefore its true colour is white, but as sunlight travels through the atmosphere it changes. The wavelengths of light at the blue end of the spectrum are much shorter than those at the red, so collisions with particles in the air are more likely. During the day, blue light scatters high in the atmosphere, giving the sky its blue colour and making the Sun appear yellow. In the morning and evening, the light that hits the ground has farther to travel, so this effect becomes more extreme. Most of the shorter blue wavelengths scatter before they hit the ground, giving sunrise and sunset their characteristic red-orange hue.



4 EARTH IS CLOSER TO THE SUN IN SUMMER

Most people know Earth doesn't travel around the Sun in a perfect circle, so it's easy to see why some make the leap and assume that the seasons are caused by the distance to the Sun, but the idea doesn't hold up when you think that the Northern and Southern Hemispheres experience summer at different times of the year. Earth's orbit isn't as elliptical as people imagine. Over the course of a year, the distance between Earth and the Sun varies by just 5 million kilometres (3.1 million miles) – that's only about three per cent. What's more, during winter in the Northern Hemisphere, we're actually closer to the Sun than we are in summer.

The real reason for the seasons is the axial tilt of Earth. As the year progresses, light hits the Northern and Southern Hemispheres at proportionally different angles and for different amounts of time every day. During winter, the days are short and the light strikes the atmosphere at a low angle, glancing through the gases as it travels towards the surface and spreading out as it reaches the ground, distributing the energy. During summer the days are much longer and the sunlight hits Earth at a steep angle, taking a more direct path towards the floor and concentrating the energy into a smaller area.

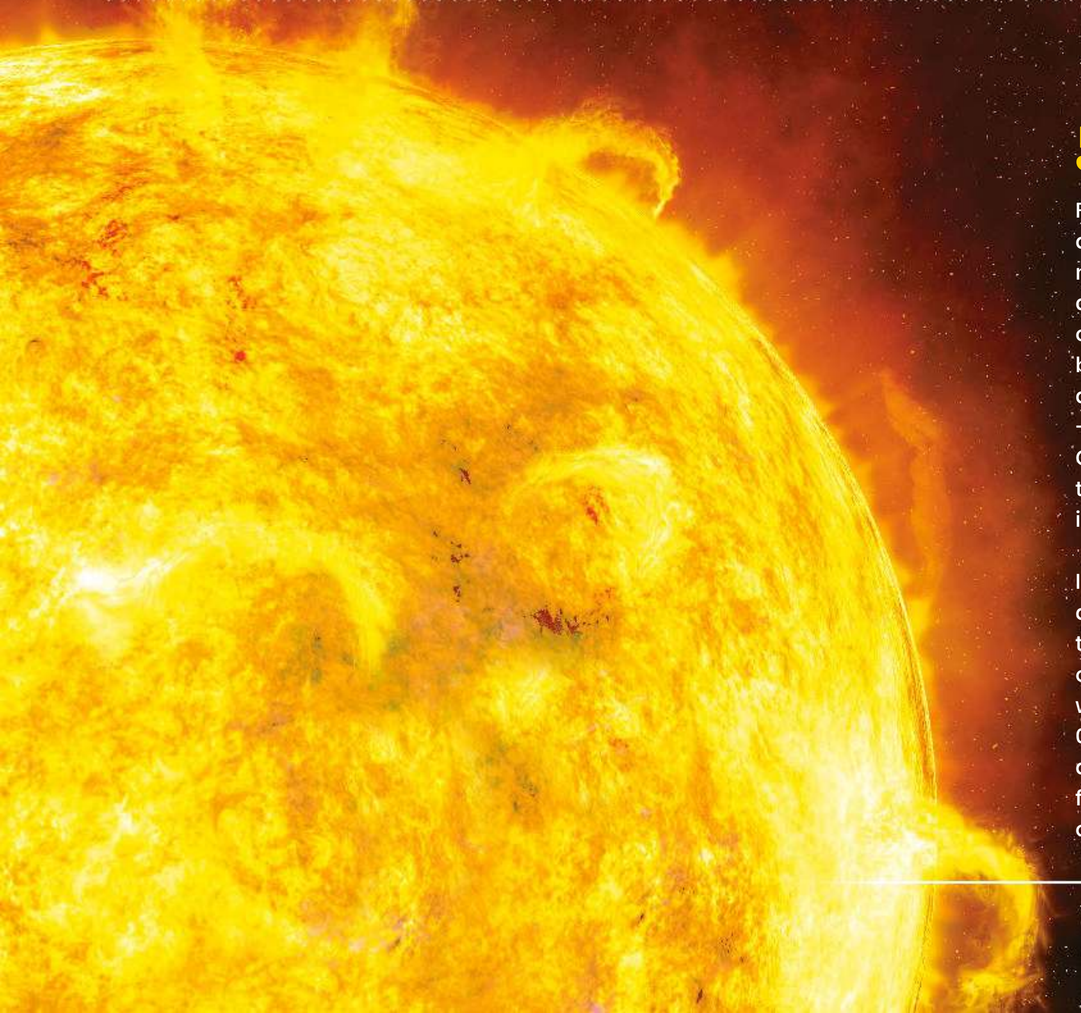


1 December
In December the Northern Hemisphere tilts away from the Sun. Day lengths are shorter as a result.

2 Axial tilt
Earth's axis points in the same direction. As the year goes by, different parts of Earth end up facing the Sun.

3 March and September
In spring and autumn, the axis is lined up parallel to the Sun. The length of a day evens out.

4 June
The Northern Hemisphere receives direct sunlight and the days are longer, raising the temperature.



5 THE SUN IS BURNING

Fire needs three things to survive: fuel, heat and oxygen. The Sun has fuel, as it's composed mainly of hydrogen and helium gas. Helium is an inert element and doesn't burn like some of its volatile neighbours on the periodic table, but hydrogen is highly flammable. The Sun also has an enormous amount of heat energy – its surface is an Earth-melting 5,500 degrees Celsius (9,932 degrees Fahrenheit). However, there's no oxygen in space, so the fire triangle is incomplete for the Sun.

In reality, the Sun isn't actually a ball of fire. Instead, the heat and light that it produces are the result of thermonuclear fusion. Inside the high-pressure, high-heat environment of our star, high-speed hydrogen atoms come within one femtometre of each other – that's 0.000000000000001 metres. A collision at this distance allows the two nuclei to fuse together, forming helium and releasing huge quantities of energy as gamma-ray radiation.

© Alamy

6 THE MOON HAS A DARK SIDE

The dark side of the Moon has inspired studio albums, novels, television series, films and video games, but the Moon itself is not quite what it seems. We only see one side of the Moon from Earth, but just because we can't observe the other side, it doesn't mean that it's dark.

Looking at the phases of the Moon easily disproves this myth. During a full Moon, the side that we can see is fully illuminated and the other side really is in complete darkness, but at any other time of the month we can only see part of the Moon. The rest of the light is falling on the far side, or the so-called dark side.

For photographic evidence, you only have to look at the first-ever images of the far side of the Moon, captured in 1959 by the Soviet Union's Luna 3, showing how it was perfectly lit up by the Sun. Not only do these images dispel the myth that the dark side of the Moon receives no light, they also show that the rock is actually lighter in colour than the side that we can see, making our side the true dark side.

1 New Moon

At the start of each lunar cycle, the Moon comes between Earth and the Sun, so the Sun's light is actually illuminating the dark side.

2 Half lit

As the Moon waxes and wanes, light falls on both the near side and the far side of the Moon at the same time, so we only see part of it.

3 Full Moon

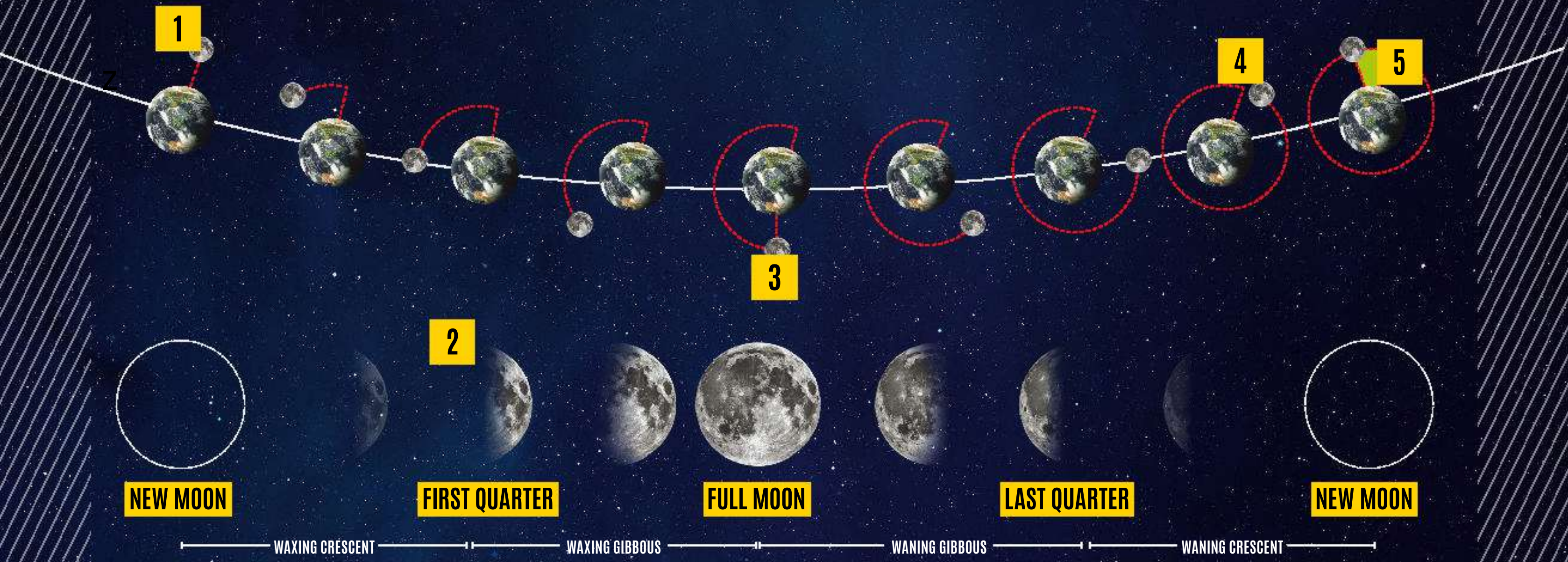
By the time the Moon has completed half of its orbit, it's fully visible in the sky. The side that we see is directly facing the Sun and the dark side really is dark.

4 Full circle

By the time the Moon has completed an orbit around Earth, its entire surface has been exposed to the Sun, meaning that there's no literal dark side.

5 View from Earth

The Moon is tidally locked to Earth, meaning that as it orbits it spins to face us so we only ever see the same side. The other side is commonly known as the dark side.



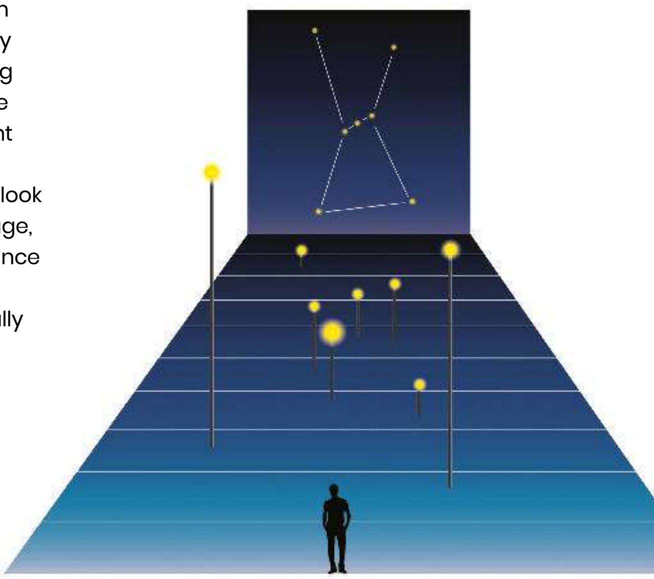
7 METEORITES ARE HOT

As meteorites pass through the atmosphere, they heat up so rapidly that the surface rock begins to melt. However, it's a bit like searing a steak: although the outside becomes intensely hot, the inside remains cool. The melted rock forms a crust just a millimetre (0.04 inches) thick. By the time a meteorite hits Earth, it is likely to be only slightly warm to human touch.

8 STARS IN CONSTELLATIONS ARE CLOSE TOGETHER

The stars in the night sky are arranged into 88 constellations that represent, among other things, 29 inanimate objects, 19 land animals, nine birds and a dragon. These recognisable groupings have guided farmers and travellers for thousands of years, but in terms of proximity they're not really groups of stars at all. Despite appearing to be close together, the stars that form the constellations are often separated by tens or hundreds of light years, extending backwards into space. From our vantage point on the surface of Earth, Orion might look like a warrior with a shield, but from elsewhere in the galaxy the stars would look distant and unconnected. They vary in age, size, type and brightness, and it's by chance that we see them in groups.

Constellations might not be scientifically meaningful groups of stars, but they do help break up the sky into recognisable and manageable chunks. By making associations between patterns in the stars and familiar animals or objects, the names and positions of individual stars suddenly become much easier for astronomers to remember. This is one of the few occasions when myths can be a good thing, because the mythology and stories surrounding each of the constellations helps fix them in people's minds.



9 EARTH'S SHADOW CAUSES THE LUNAR PHASES

It seems plausible that the lunar phases are the result of Earth's shadow, but the Moon is often visible alongside the Sun during the day, so what's really causing the lunar phases? They're actually the result of the Sun rising and setting over the visible side of the Moon as it orbits Earth. During a full Moon, our satellite is on the opposite side of Earth to the Sun, so we see the sunlight illuminating its entire visible surface. However, during a new Moon the Moon comes between Earth and the Sun, so the light falls on the side that we cannot see. In the intervening days, the amount of light that we can see on the lunar surface gradually increases and decreases with the orbit of the Moon.

A lunar eclipse is the only time that Earth casts a shadow on the Moon, and these rare events only occur if Earth comes exactly between the Sun and the Moon, temporarily blocking out the light.

10 YOU CAN SEE THE GREAT WALL OF CHINA FROM SPACE

The Great Wall of China is the longest human-made structure in the world and spans an incredible 21,196 kilometres (13,171 miles). The idea that it might be visible from outer space is a popular one and has been around since the 1930s, but unfortunately it is only partly true.

The Great Wall might be very long, but it's not remotely as wide – just over six metres (20 feet) at its base. Not only that, it's constructed from materials that blend well with the surrounding terrain. In low-Earth orbit, which starts at 160 kilometres (99 miles) altitude, the wall is easy to pick out on radar images but is invisible to the naked eye. During his time on the International Space Station (ISS) in March 2013, Chris Hadfield tweeted: "I did not see the Great Wall of China from space and neither did the Chinese astronauts. With a big enough camera lens and clear air, maybe."

© NASA; Getty

11 RE-ENTRY SPACECRAFT HEAT UP BECAUSE OF AIR FRICTION

As a wide, blunt spacecraft plummets through the atmosphere, molecules of gas cannot move out of the way fast enough and they start to stack up, forming a cushion beneath the craft. This keeps most of the gas away from the surface, preventing heat from transferring to the vehicle. Frictional heating contributes to the temperature rise, but the pressure achieves the real heating. The closer the compressed molecules come to one another, the higher the temperature climbs. Eventually, the pressure becomes so intense that the molecules start to tear apart, creating a layer of charged plasma and producing a searing plasma corona.

12 MERCURY IS THE HOTTEST PLANET IN THE SOLAR SYSTEM

Venus, which orbits nearly twice as far from the Sun as Mercury, has an average temperature of 462 degrees Celsius (864 degrees Fahrenheit). The difference is down to the atmosphere. On Venus, the atmosphere is thick and composed mainly of carbon dioxide, trapping the heat in an insulating bubble, while Mercury has a very thin atmosphere.

13 SATURN IS THE ONLY RINGED PLANET IN THE SOLAR SYSTEM

When people think of planets with rings, there's only one that springs to mind. Saturn is well known for its seven main rings. There's no denying that they are incredibly photogenic, but they aren't the only ones in the Solar System. Jupiter, Uranus and Neptune all boast their own set of rings, although nobody could be certain they existed until the Voyager flybys in the 1970s and 1980s.

14 STARS TWINKLE

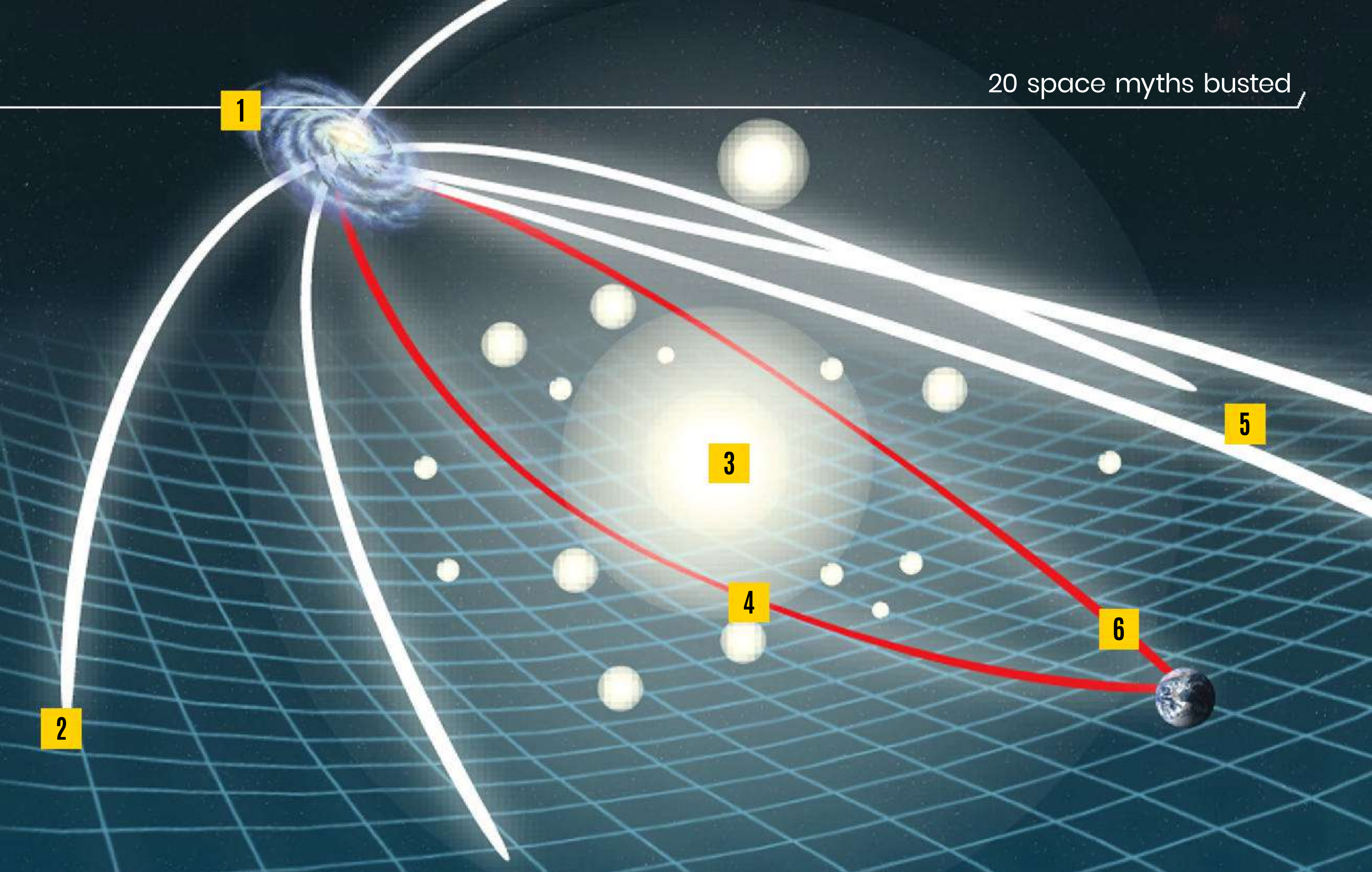
A famous nursery rhyme is responsible for this myth, but although stars appear to twinkle in the sky, the flickering is just an illusion. It might seem plausible that a star would twinkle as it shines, but at this distance the light that we see from them is actually very steady.

As light travels towards Earth, it passes through the gas molecules that make up our atmosphere. These are not static and they swirl as turbulence stirs the atmosphere. This deflects some of the light, making it look like the light is shifting and twinkling. The more atmosphere the light has to pass through, the more likely these shifts are to occur, making stars near the horizon appear to twinkle more.

15 LIGHT ISN'T AFFECTED BY GRAVITY

Gravity is an attractive force between two objects with mass, and light is transmitted by photons, which have no mass, so light can't possibly be affected by gravity. But if this is true, how is it that black holes can prevent light from escaping? The laws of gravity were the work of Isaac Newton, who said that gravity is a pulling force that works when both objects involved have mass. However, Albert Einstein overhauled this theory by suggesting it was the result of the shape of the fabric of the universe.

Imagine placing a heavy ball on a sheet of rubber. The rubber stretches, creating a dent. If you try to roll a smaller ball from one side of the sheet to the other, instead of travelling straight, it will have to curve. This is what the stars and planets do to the dimensions of space-time. These curves don't just affect objects with mass, but light travels so fast that the dips in space-time have little effect on it. But black holes create space-time curves that bend towards infinity, so not even light can climb out the other side.



1 Galaxy The light from distant galaxies can be seen from Earth, but the pictures that we capture don't always match what is really there due to gravitational lensing.

2 Cosmic magnification This phenomenon is known as gravitational lensing because the curve in space-time bends light like a lens.

3 Galaxy cluster This massive cluster of galaxies between Earth and the distant galaxy has created an enormous curve in space-time.

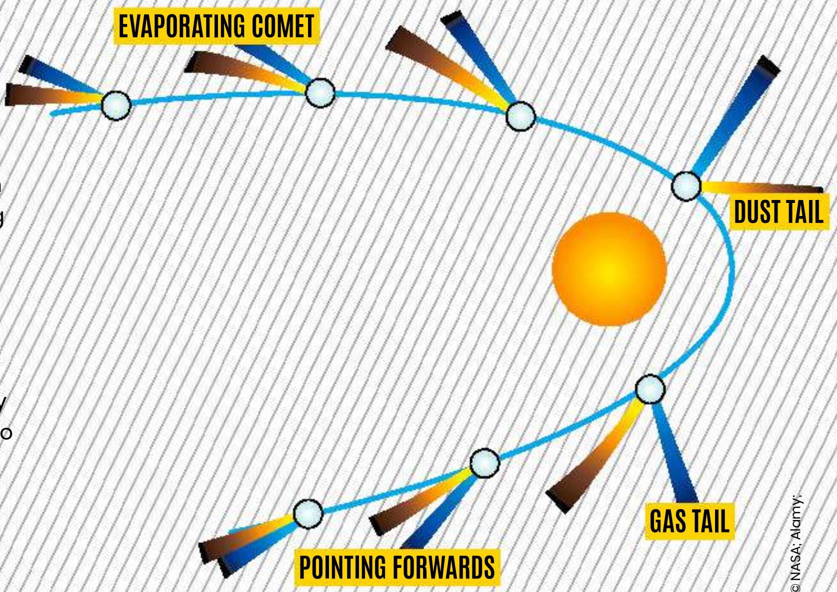
4 Lensed image The path of the light is bent so much that the image appears more than once in the sky – as a duplicate or as streaks or rings.

5 Space-time This two-dimensional representation of space-time gives an idea of what is really happening in the four dimensions of space and time.

6 Bent path The photons of light released by the distant galaxy curve their paths as they travel past the massive cluster of galaxies.

16 COMET TAILS INDICATE WHICH WAY THEY'RE HEADING

Comets are essentially lumps of dirty ice. As they approach the Sun they heat up, releasing gas and dust. We would expect the resulting tail to point backwards, like the streak of a falling meteor, but in space there's no air. Comets are shaped and blown by radiation pressure and the solar wind, so they always point away from the Sun. High-energy ultraviolet light crashes into the evaporating gas of the comet, stripping away electrons and forming charged ions. These get caught up in magnetic field lines and shoot directly away from the Sun in a blue ion tail. At the same time, dust is released into space, forming a tail of particles as fine as smoke. Photons of light from the Sun create an intense bubble of pressure which pushes against the dust, guiding it into a wide streak that curves around the path of the comet's speedy orbit.



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17 YOU CAN HEAR SOUNDS IN SPACE

The sound of an exploding vehicle on Earth is transmitted by a pressure wave, which travels through fluids like air or water when vibrating particles bump into one another and pass some of their energy on. In space the particles are so far apart that sound waves cannot propagate, so although the source of an explosion would vibrate, the movements have nowhere to go. Outside of Earth, only on planets with atmospheres would we hear sound.

18 SPACE IS AN EMPTY VACUUM

Space is closest to a true vacuum in the universe and is far emptier of any particles than anything we can produce on Earth. However, there's so much hydrogen in the universe that a few atoms can still be found in every cubic metre of space. It's a vacuum compared to the atom-rich atmosphere of Earth, but it's not perfect. Nowhere in space can be guaranteed to be a true vacuum in the strictest sense.

19 THERE'S NO GRAVITY IN SPACE

Craft like the ISS are constantly under the influence of Earth's gravity – that's what keeps them in orbit. The weightlessness that the astronauts experience is because they are falling gradually towards Earth. Gravity compels the ISS towards the ground, but the space station is moving so quickly that it shoots over the horizon, falling around the curvature of the planet instead of coming back down to Earth – essentially, the astronauts inside are in a constant free fall.

© NASA

20

WE EXPLODE IN SPACE WITHOUT A SPACESUIT

Our bodies are adapted to exist under the pressure of Earth's atmosphere. When this is removed, water in our tissues starts to evaporate and the body starts to swell. Human skin is stretchy enough that this does not lead to an explosion, but after around ten seconds of exposure, people become unconscious. This happened to an unfortunate spacesuit technician during a NASA test in 1966 after some equipment failed, but thankfully the pressure was restored after just 30 seconds and the technician recovered.

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FUTURE TECH

SPACE FUEL DEPOTS

Are launch costs holding up your mission plans? A group of researchers from MIT may have the answer in the form of a service station in space

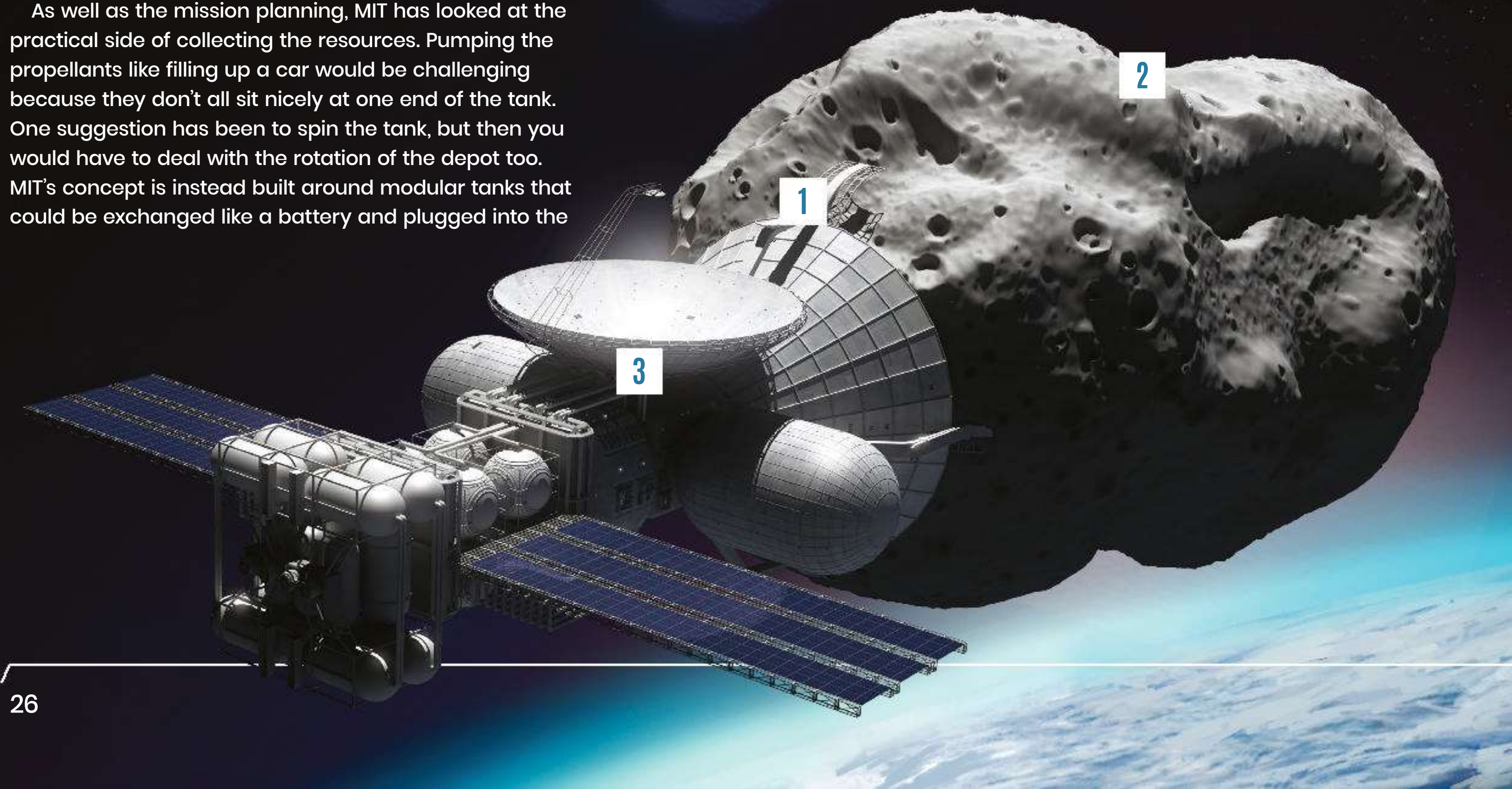
Getting into space is hard. With the engines and rockets we have now, the majority of the weight of a rocket at launch is fuel and oxidiser to overcome Earth's gravity. And if we want to go beyond Earth orbit, the problem gets even worse. If you could fuel up your interplanetary mission in orbit instead of having to launch everything in one go, the cost of individual missions could be cut significantly. With this in mind, a team from the Massachusetts Institute of Technology (MIT) has proposed an intermediate concept that could build up propellant depots with traditional missions.

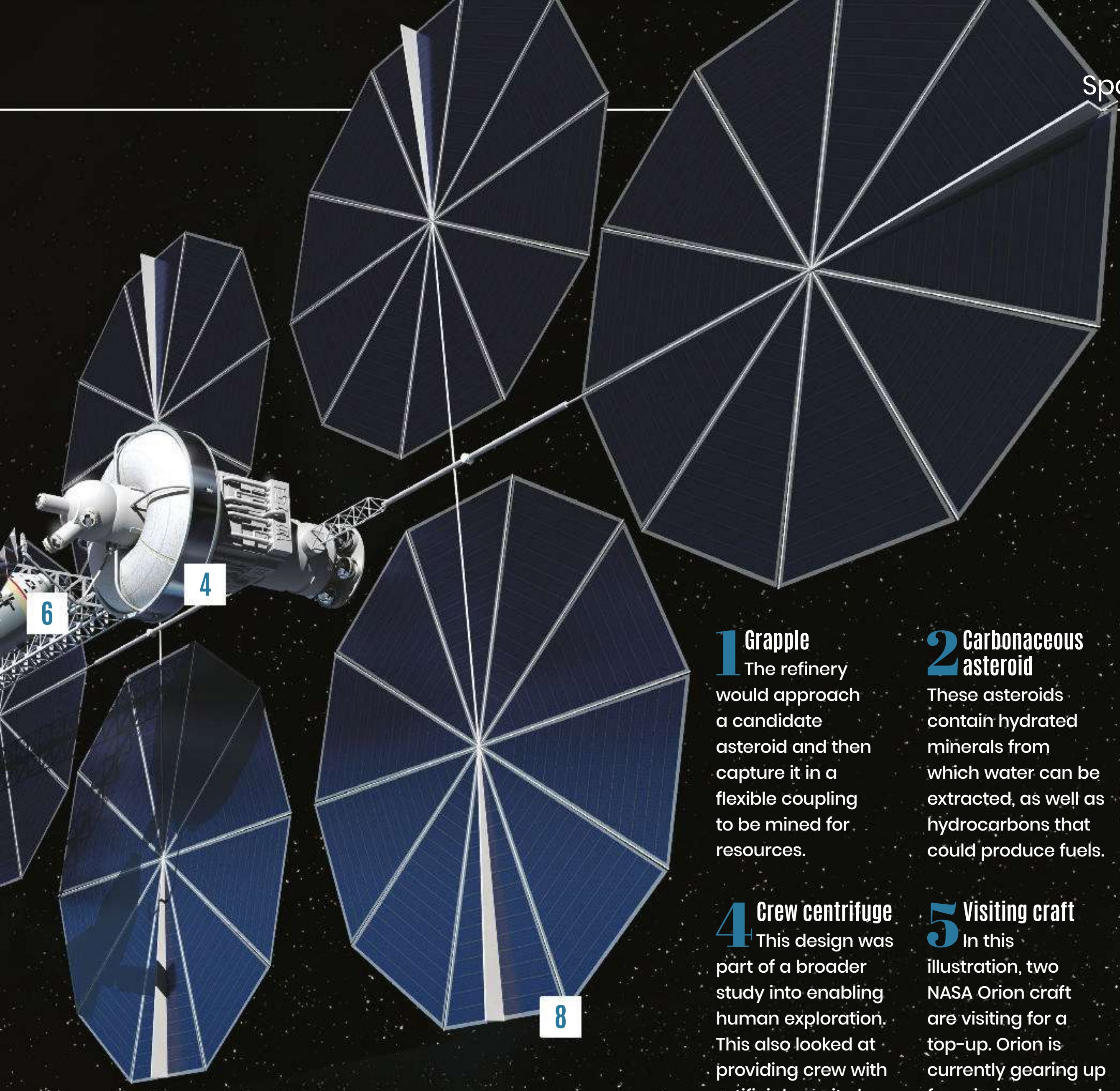
Led by Professor Jeffrey Hoffman, himself a veteran of five Space Shuttle missions, the team proposes to take advantage of contingency propellants that would be carried on lunar missions anyway. This is the surplus that must be there to cope with mission problems – if everything goes to plan then these unused reserves could be left in space to establish a depot. The depot could then be used in two ways: first, in a steady-state situation where each mission collects its contingency propellant. With the cost of sending anything beyond Earth orbit being so high, even this would be an important saving. Second, smaller missions could keep launching with a contingency so that a stockpile accumulates at the depot. This means much more ambitious missions could be launched with minimal propellant and collect the stockpile.

As well as the mission planning, MIT has looked at the practical side of collecting the resources. Pumping the propellants like filling up a car would be challenging because they don't all sit nicely at one end of the tank. One suggestion has been to spin the tank, but then you would have to deal with the rotation of the depot too. MIT's concept is instead built around modular tanks that could be exchanged like a battery and plugged into the ship ready for use. These modules would remain available in space as part of the whole depot system.

The ideal would be to live off the land – after all, we may still be filling in the map of Earth if explorers had been forced to take everything they needed with them. We want to get to the point where we only have to launch people and luggage and source everything else in space. That could be where Deep Space Industries (DSI) comes in, and its first step is propellant depots.

DSI is working on a number of technologies to enable space mining, refining and manufacturing. After an initial reconnaissance phase to identify suitable asteroids and return samples, the company intends to start mining metallic materials and using its own special design of 3D printer to build hardware from them in space. Along with mining, the company plans to refine propellants and water from asteroids, returning to Earth orbit for sale. This would finally enable missions to launch completely empty and pick up all their heavy propellants in orbit.





1 Grapple

The refinery would approach a candidate asteroid and then capture it in a flexible coupling to be mined for resources.

2 Carbonaceous asteroid

These asteroids contain hydrated minerals from which water can be extracted, as well as hydrocarbons that could produce fuels.

3 Parabolic dish

A large parabolic dish could ensure easy communications with Earth, or could be utilised as a solar collector for solar thermal power.

4 Crew centrifuge

This design was part of a broader study into enabling human exploration. This also looked at providing crew with artificial gravity by employing spinning crew quarters.

5 Visiting craft

In this illustration, two NASA Orion craft are visiting for a top-up. Orion is currently gearing up for missions beyond Earth orbit and to the Moon.

6 Robot arm

The spacecraft would approach until the depot can grapple it with a robot arm. The arm will then provide the propellants directly to remove the need to hard dock.

7 Propellant tanks

These are intended to be launched as rocket stages themselves before being attached to the depot. Here they are shown with engines still attached.

8 Solar panels

The most likely location for this sort of depot is one of the Lagrange points. Being in the same solar orbit as Earth, there will be plenty of solar energy available for panels.

> "We want to get to the point where we only have to launch people and luggage and source everything else in space"

© Adrian Mann; Jay Wong

BIO+

Simon Morden

Morden is a British science-fiction author, best known for writing the Metrozone series of novels set in post-apocalyptic London. He is the former editor of science and technology magazine *Focus*, has featured on the Arthur C. Clarke Award judging panel and is the recipient of the Philip K. Dick Award. Morden holds a degree in Geology from the University of Sheffield and a PhD in Geophysics from Newcastle University.

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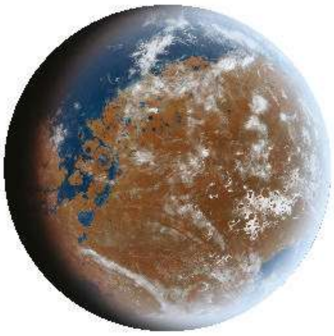
Simon Morden

"If life is simply a question of the right environment, then yes, Mars had life"



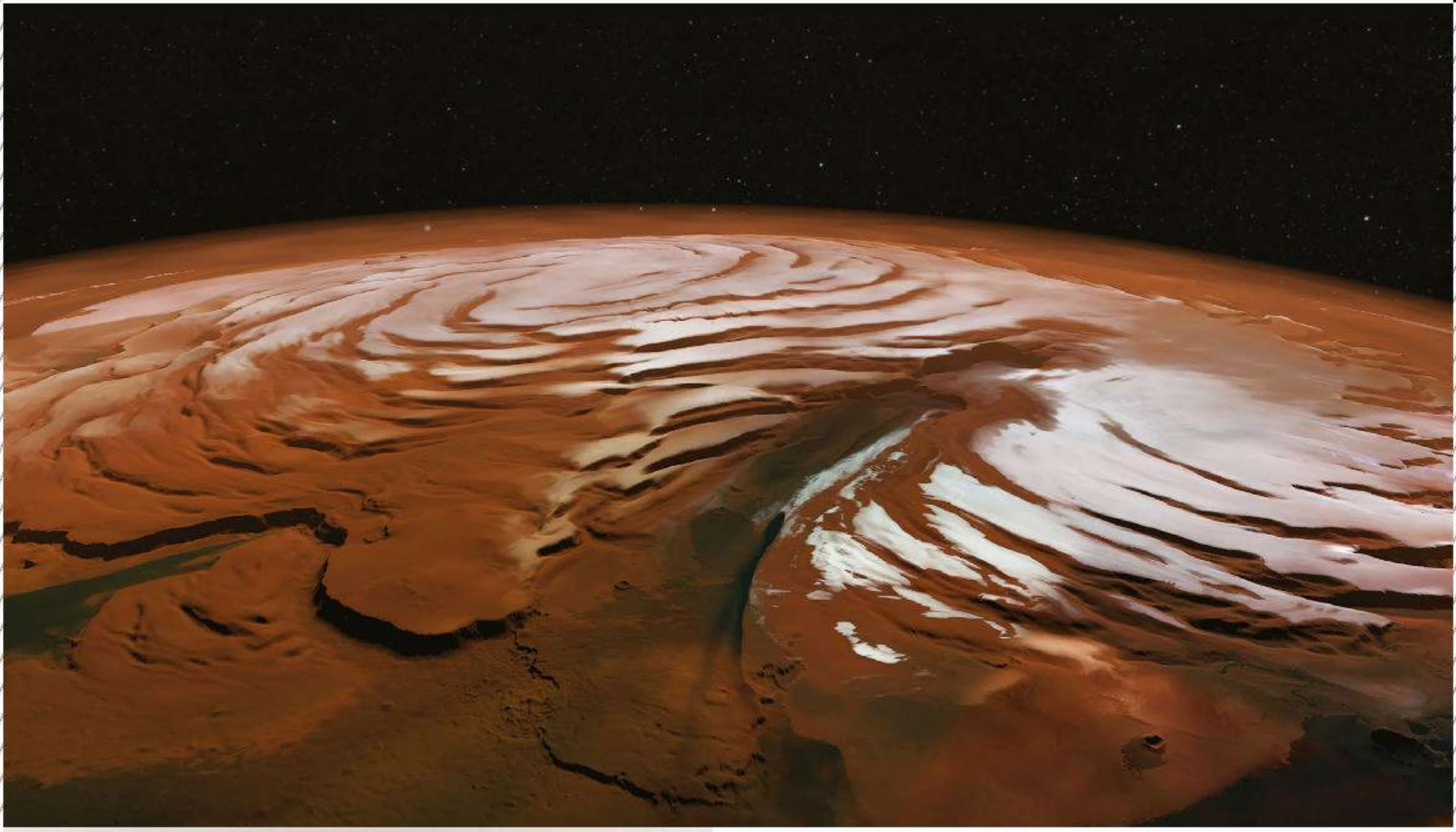
Planetary scientist and award-winning science-fiction writer Dr Simon Morden talks to All ***About Space*** about his obsession with Mars and his latest science-fact book on the Red Planet

Interviewed by Ben Biggs

In *The Red Planet: A Natural History of Mars*, you vividly describe what it's like to be on ancient Mars. How much of this is scientific fact versus artistic licence?
Over the last 50 years, we've built up a considerable body of evidence that tells us what Mars was like at various points in its long history – what the climate was like, what the volcanoes were doing, where the rivers and lakes and oceans were – so while it's an act of the imagination to describe what it would feel like to sail on the Martian sea or sample gases erupting from fissures on primordial Mars, everything there is backed by peer-reviewed papers.

Do you think life ever existed on Mars? If so, do you think we'll ever find evidence of it?
A lot turns on the answer to the question how

▲ Ancient Mars could have been covered with oceans, a lot like Earth today



The Martian north pole and Chasma Boreale, taken by the Mars Express orbiter

Mars Express took this photo of Korolev crater, found in the northern lowlands and filled with ice

inevitable is life?. If life is simply a question of the right environment, then yes, Mars had life. Conditions in the early Martian ocean were pretty much identical to those in early terrestrial ones: there would have been mineral-rich hydrothermal vents pouring a cocktail of energy-producing chemicals into the deep seas. If those chemicals had the same capacity for self-organisation as they did on Earth, then simple life would have spontaneously appeared.

It's a very long way from a single-celled organism to something we might recognise as a fossil, though. Until we get a lot more rocks, and from the right places – the ancient ocean floor, specifically – we won't be able to say with any confidence one way or the other.

Where would you like to see the next lander or rover mission go, and why?

For the reasons above, I'd like to put something down on the vast plains of the north, where there was once a deep ocean. I'd be looking for those relics of hydrothermal vents and having a really good dig around. If we can identify some of them from orbit, even better.

What do you think the next really big Mars discovery is likely to be?

If the science is correct, then Mars has had continuous volcanic activity for almost its entire history – from the very earliest volcanoes we can identify to the very latest ones on the plains south of Elysium. Those lava flows appear to date from barely a few million years ago, so I remain sceptical that the planet has actually decided that now, relatively speaking, is the time to stop erupting. Active volcanism on Mars is my call.

NASA is targeting the early 2040s for the first boots on Mars. What could astronauts do there that robot missions can't?

The robots are absolutely brilliant, and our ability to get them there and have them (mostly) work is at the very limits of our technology. But people bring a whole different skill set to bear. They're adaptable – an

> "Putting people on another planet will inspire a whole new generation of scientists and engineers, and writers and artists too"

astronaut is able to carry out a vast range of tasks. They're also much faster decision makers. It takes, at best, minutes to send a message to Earth and have a controller decide what the robot will do next, then minutes more to send the instruction and yet more minutes to see if that worked. A human on the ground will be able to cover more ground and do more science, even if their time on the surface is limited by other factors. There's also the undeniable wow factor, which mustn't be discounted. Putting people on another planet will inspire a whole new generation of scientists and engineers, and writers and artists too.

Do you think it would be worth terraforming Mars in the distant future?

I think terraforming is very much the grand folly of projects. If our technology is advanced enough to turn Mars into an Earth-like world, we wouldn't need to. That same technology would be more than sufficient for us to transform not just the way we live on Earth, but the way we'd live in space. Building vast orbital habitats around any planet we choose would be an order of magnitude easier and faster than any terraforming scheme.

What's your favourite geological feature of Mars, and why?

This is worryingly like asking me which is my favourite child! There are many candidates, but I think I'd have to go for Korolev crater. It sits on the high northern plains, is almost a perfectly circular 80 kilometres (50 miles) across with high, defined walls and inside it is a vast lens of bright water ice that stretches 60 kilometres (37 miles) side to side and nearly two kilometres (1.2 miles) tall. It's startling and beautiful.

Was there a point when Mars and Earth were much more similar than they are now, and what made them go off on different evolutionary trajectories?

Very early on – the first 600 to 700 million years, possibly up to a billion years – both planets would have superficially looked similar: barren land, oceans and lakes that may or may not have had simple life. But the differences between Earth and Mars were baked in from the very start, and it just took some time to unwind. Mars is significantly smaller, and for whatever reason it couldn't sustain either a system of plate tectonics, which recycles the crust and moves water into the deeper mantle layer, or a planetary magnetic field that protects the atmosphere from being stripped by the Sun's radiation. Earth remained a rich, dynamic planet, while Mars slowly became a gasping, stagnant one.

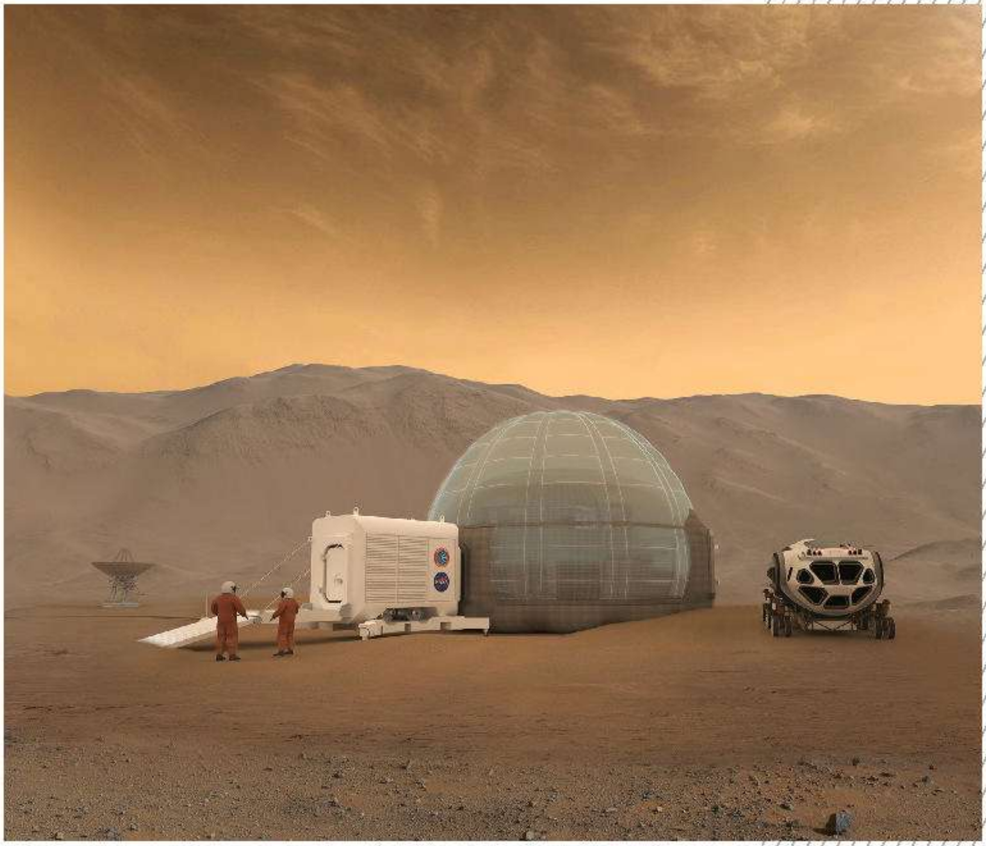
Mars has changed radically from one era to the next. What does the next billion years hold in store for the Red Planet?

One of the curious things about Mars is that because it doesn't have a large moon to stabilise its axis of rotation, it flops around in an entirely chaotic and unpredictable manner. Currently, the axis is at 25 degrees to the orbital plane, similar to that of Earth, and it has summer and winter seasons just like us. But in the past the axis has been anywhere between 0 and 60 degrees, and this has enormous effects on the Martian climate. If the axis was at 40 degrees, both ice caps would melt and we'd see free water on the surface of Mars again. And this wouldn't take a billion years… a few thousand would do it.

***Total Recall* or *The Martian*?**

At least you didn't ask me to choose between *War of the Worlds* and *John Carter of Mars*! The problem with *The Martian* – as epic as it is – is that I know too much and can see where the science has been tampered with. *Total Recall* doesn't pretend to be accurate at all – everything there is to service the lurid plot. So as much as I enjoyed Matt Damon's survival antics on the Red Planet, I'll go with Arnie and get my ass to Mars.

***The Red Planet: A Natural History of Mars*, written by Simon Morden, is out now in hardback and paperback**



An artist's concept of a Mars ice home, a temporary habitat for the first astronauts sent to the Red Planet

© NASA-ESA

HOW TO
BUILD A GALAXY

The making of these billion-star structures has been puzzling astronomers for decades. All About Space puts together the pieces for building a galaxy

The universe is packed with galaxies. Everywhere we look we see galaxies crammed into the cosmos, grouped in clusters and great sheets that are littered throughout space-time. The most distant galaxies ever seen have been identified by the Hubble Space Telescope as being 13.4 billion light years away. Yet these are not even the most distant galactic structures out there. It's the first galaxies that hold the record for being the furthest away from us. However, we're yet to see them. To do so we will need the infrared prowess of the recently launched James Webb Space Telescope (JWST), which will be able to see galaxies as they formed just 300 or 400 million years after the Big Bang – the event that threw the cosmos into existence.

Understanding how galaxies form is a bit like trying to put a jigsaw puzzle together. Think of each galaxy as being a piece of that puzzle. Because galaxies are so old and evolve so slowly, when we see a galaxy in the night sky we are just seeing a single snapshot of its long life. However, the galaxies are all at different stages of their evolution, so if we can put all these snapshots together – just like arranging the pieces of a puzzle – we can build an overall picture of how galaxies like our own Milky Way grew into the star, dust, gas and dark matter-packed structures we see today.

We've actually only known that there are galaxies in the universe beyond our own Milky Way for around a hundred years. Before that time astronomers thought that the weird objects they dubbed 'spiral nebulae' were still part of our galaxy. Their telescopes weren't powerful enough to resolve individual stars in these objects, although when astronomers looked at the light coming from them, they had all the evidence they

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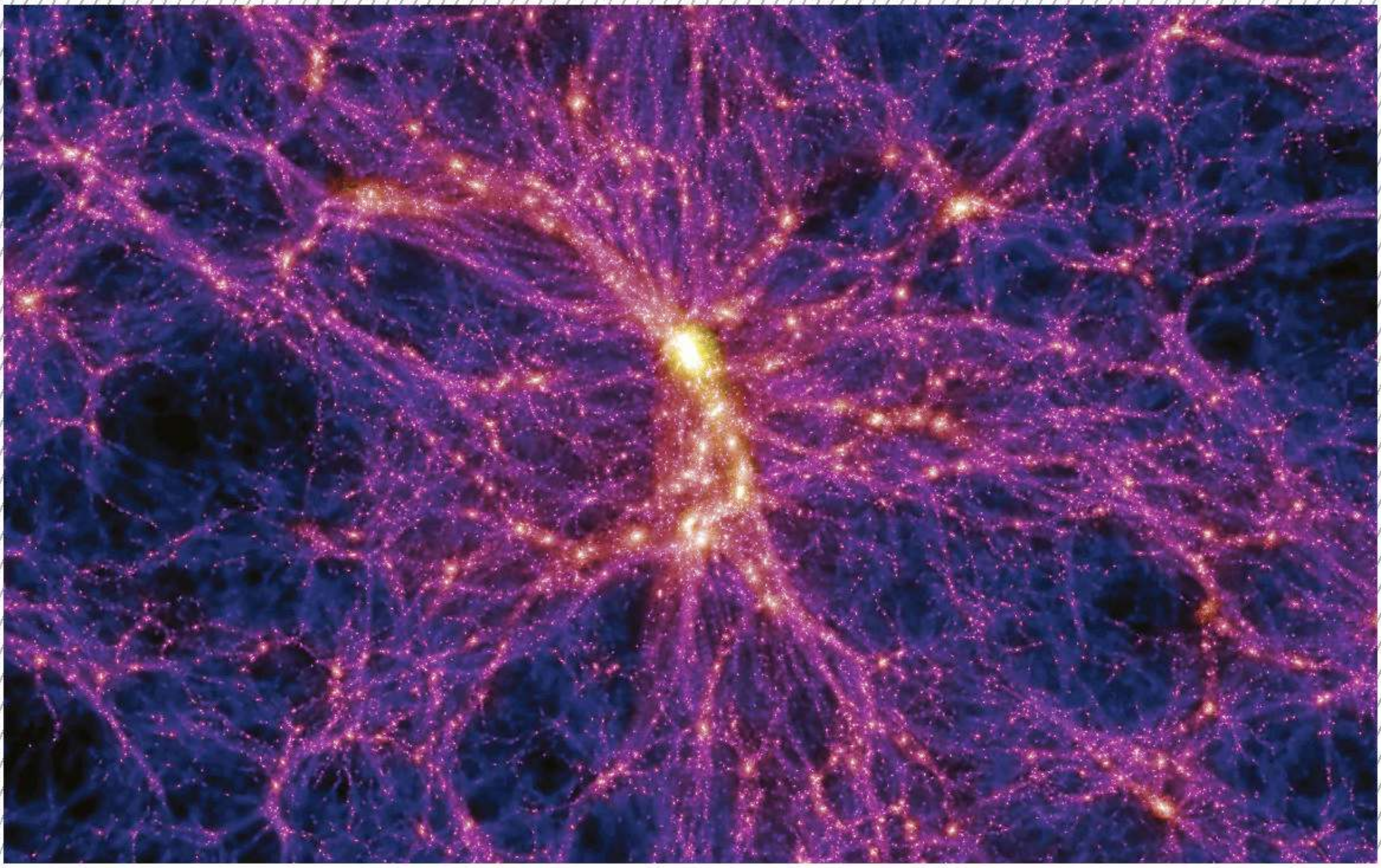


The filaments that make up the large-scale structure of the universe can be broken down into clusters and superclusters of various galaxies

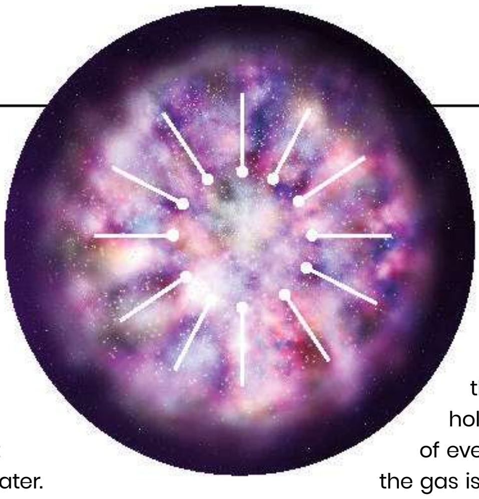
© NASA; ESA; Tobias Roetsch

needed to confirm that these blobs in the night sky were made up of many stars. However, in 1912, American astronomer Vesto Slipher found that the light being thrown out by the spirals was Doppler shifted towards redder wavelengths, showing that the 'spiral nebulae' are moving away from us and take on a red tint. Doppler shift is the compression or stretching of light waves as an object moves towards or away from us. You might not have realised it, but you have experienced a Doppler shift before since it also happens with sound waves. When a police car or ambulance has raced past you with its siren blaring, the pitch of the sound it makes changes depending on its distance. At first it is higher, becoming lower as it moves away since the sound waves become compressed and then stretched.

In 1925, Edwin Hubble announced he had discovered that the spiral nebulae were all galaxies, or 'island universes', far beyond our own. He achieved this thanks to the biggest telescope in the world at the time – the 2.5-metre (8.2-foot) Hooker Telescope at Mount Wilson Observatory in California. Hubble was able to resolve individual stars, including a specific type called a Cepheid variable. This type of star throws out light which varies according to its true brightness, and from this observation astronomers can work out their distance. It was the Cepheids found in our neighbouring galaxy of Andromeda that allowed astronomers to measure the distance to our closest spiral as 2.5 million light years away. Coupled with Slipher's discovery that galaxies are all moving away from us, scientists quickly realised that once upon a time they must have been much closer together than previously anticipated.

Hubble's next step was to classify all of the galaxies in an effort to understand them as much as he could. It was from this that he created his famous tuning fork diagram. He built this diagram so that its handle is made up of elliptical galaxies, which are galactic structures with ovoid shapes. Hubble referred to these as early-type galaxies because he believed that all galaxies began their lives as ellipticals before evolving into one of two types of spiral galaxy, forming the prongs of his tuning fork. One type are regular grand-design galaxies with their graceful spiral arms curving away from a small central bulge, while the second type

> **"We've actually only known that there are galaxies in the universe beyond our own Milky Way for around a hundred years"**



It's thought that galaxies are made from the collapse of protogalactic clouds of dense hydrogen and helium gas in the early universe

are barred spirals, whose spiral arms are connected with a long, straight bar running through their glowing centres. In fact, today it's believed that our very own galaxy has a bar running through its centre. Hubble thought that the elliptical galaxies were the bulges of spiral galaxies without the arms, which he assumed grew later. However, astronomers changed their minds about this after studying galaxies in more detail throughout the 20th century. They found that elliptical galaxies form when two or more spiral galaxies collide and merge, and it's spiral galaxies that are really the early ones.

So how do spirals form? The main ingredients are gas – predominantly hydrogen – and the mysterious substance called dark matter. Nobody knows what dark matter is, but we know it comes in the shape of giant blobs scattered throughout the universe. Some of these dark matter blobs are large enough to hold clusters of thousands of galaxies. The dark matter came first, forming these blobs, or halos, very soon after the Big Bang. The gravity of these halos began to attract hydrogen gas towards them, which began to flow like rivers along gravitational inclines created by the influence of dark matter into the cores of the blobs. There the hydrogen formed enormous spinning clouds, and the hydrogen and dark matter formed the embryo of a galaxy – think of the white and the yolk of an egg as the dark matter with the hydrogen at the core.

Because the dark matter and hydrogen mixture was spinning so fast, it flattened into a pancake shape, taking on the characteristics of a spiral galaxy's flat disc. Meanwhile, small pockets of hydrogen gas in the cloud collapsed to form the very first stars. These stars were gigantic – hundreds of times more massive than our relatively puny Sun – and they exploded very quickly as powerful supernovae. Stars are able to create elements in their cores, while the violence of exploding stars, known as supernovae, can form even heavier elements. When the first stars detonated, they spilled their guts into the young galaxy around them, enriching it with these heavy elements. Over time, enough of these elements would build up to form asteroids, moons and planets. When we look at galaxies today, including our own Milky Way, we see vast lanes of black dust. This dust is comprised of elements made inside the nuclear furnaces of stars, dating all the way back to the first stars that existed about 13.5 billion years ago.

Today we find that the oldest parts of spiral galaxies are their bulges. In these central regions, most of the gas has been used up and the stars that exist there are crammed together and more red than the combined light of the stars in the spiral arms, which are instead dominated by hot, young stars. The exception is in the few tens of light years immediately around the supermassive black hole that lies in the middle of every large galaxy, where the gas is dense enough to keep forming new star clusters made of massive stars.

The black holes in the centres of galaxies are enormous. The black hole that lies at the heart of the Milky Way is 4 million times more massive than the Sun. In other galaxies, black holes can be tens or even hundreds of millions of times more massive. The biggest galaxies of all – the giant ellipticals found in the centres of galaxy clusters – have central black holes with masses over a billion times that of the Sun, as is the case with the galaxy Messier 87 in the heart of the Virgo Cluster.

Everyone knows that black holes like to consume matter – that's how they grow so big. But black holes can't eat everything that is served their way, and sometimes they spit out their food. As gas flows towards a black hole, it whirls around into a disc of material spiralling into the centre. However, the gas brings magnetic fields with it that become wrapped up around the black hole by the

The stars in galaxies are made from the collapse of clouds of gas and dust under their own gravity

GALACTIC EVOLUTION

How their different sizes can affect how galaxies form

1 A lonely cloud of gas

In order for what astronomers call a small galaxy to be made, a relatively large and isolated gas cloud is needed.

2 The making of stars

Under gravity, the cloud will collapse because there's not enough pressure from the gas itself to fight against it. Baby stars are made in the fight between gravity and pressure.

3 Forming a disc

The matter spins quickly, causing a flattened disc-like structure. At the centre is a bulge where the older first-generation stars can be found. The rest of the disc is teeming with younger stars.

4 A galaxy with arms

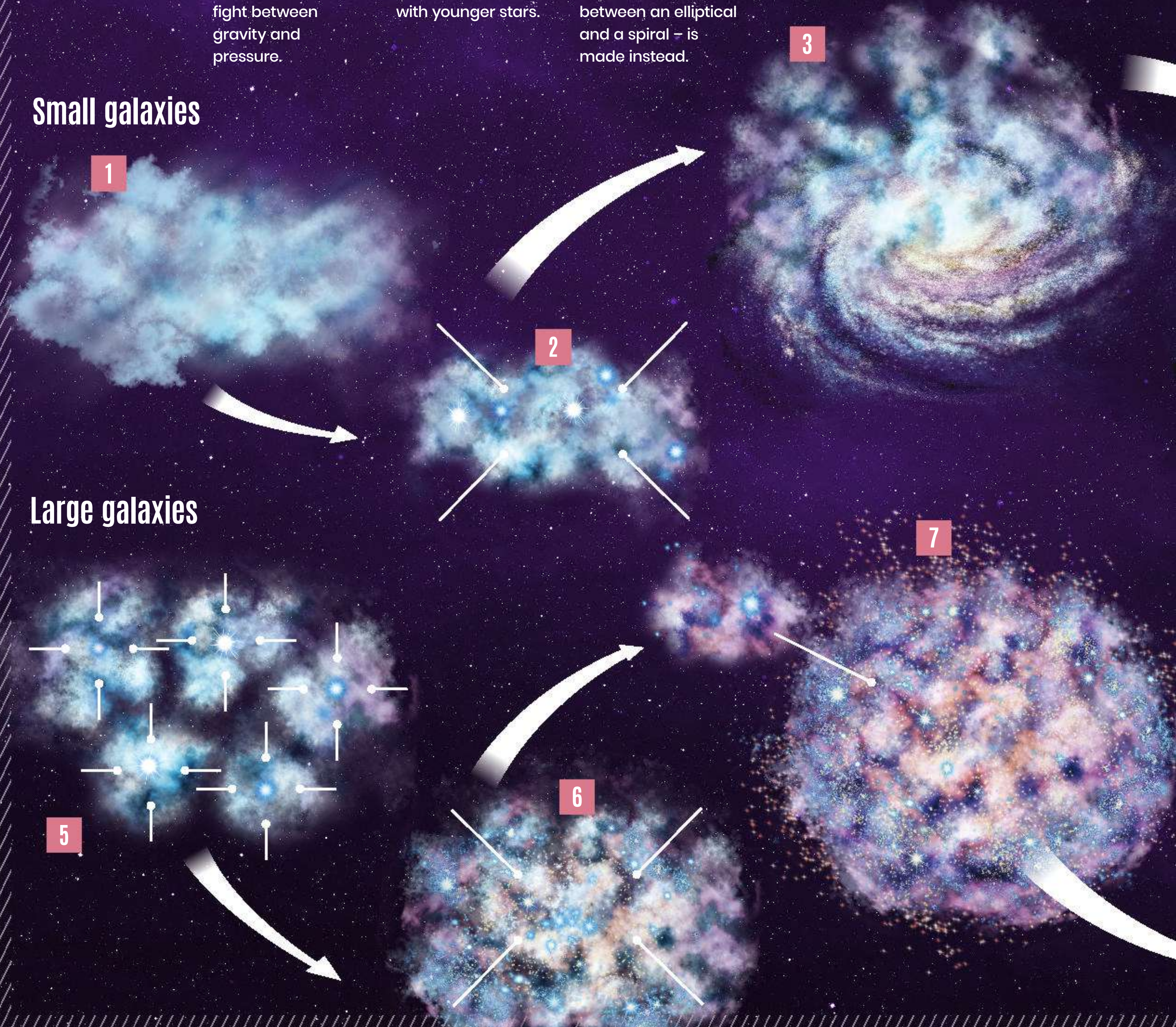
Internal processes make the arms and bars found in spiral galaxies. However, if conditions are more favourable, a lenticular galaxy – an intermediate between an elliptical and a spiral – is made instead.

5 A team of gas clouds

Small clouds of gas collapse early on to form the galaxy's very first stars.

6 A party of stars

These gas clouds, with their newly formed stars, clump together to make a larger cloud with a party of stellar populations.

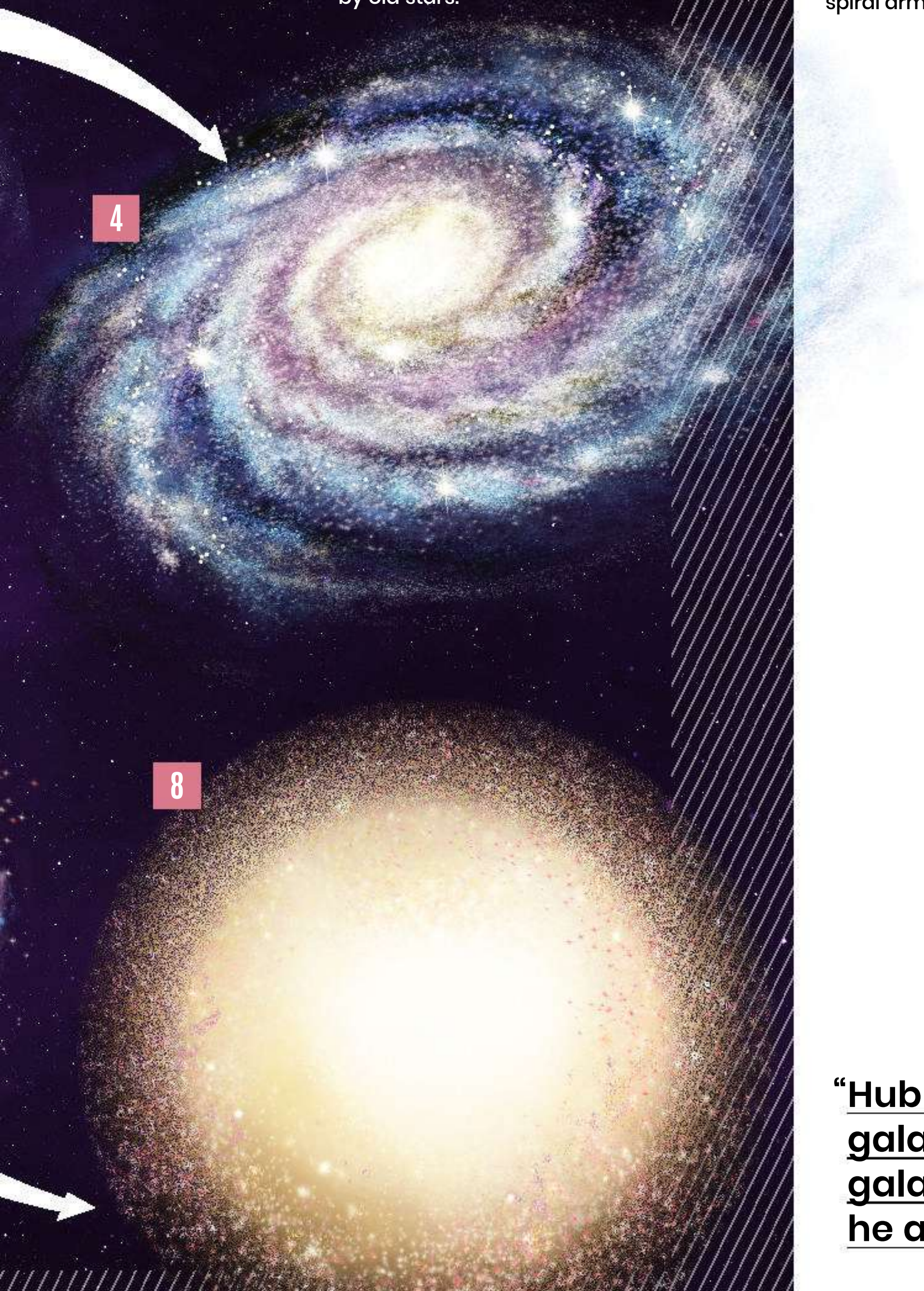


7 Gaseous add-ons

There isn't much spinning going on during the making of a large galaxy. Instead the merging of nearby gas clouds stops any chances of a disc-like structure forming.

8 A gigantic galaxy

Since most of the gas needed to make a new generation of baby stars was mopped up, no more can be made. What's left is a gigantic elliptical galaxy that's dominated by old stars.



Spiral galaxy NGC 7678 features a peculiarly prominent spiral arm

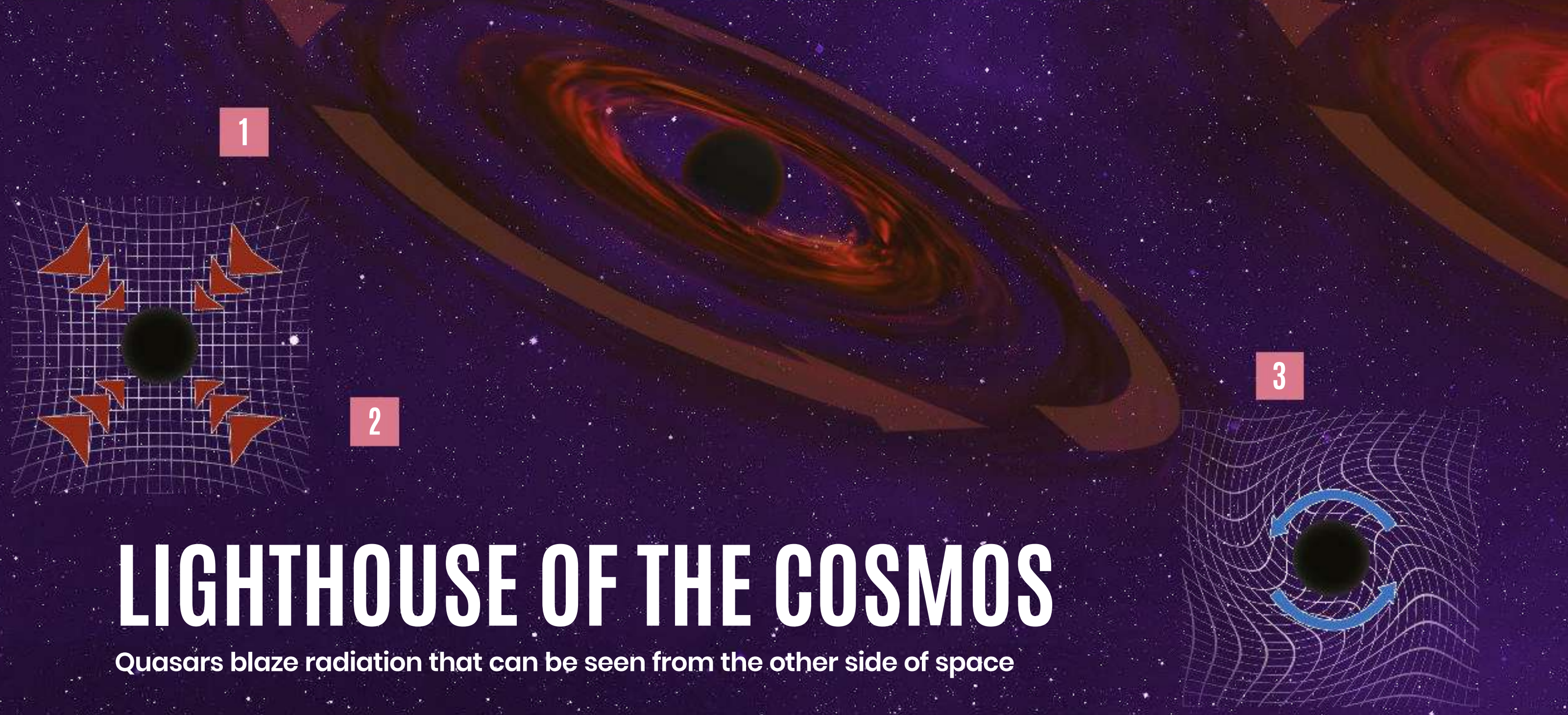
© ESA/Hubble & NASA; Tobias Roetsch

swirling gas. Eventually the magnetic fields become so strong that they can actually begin to funnel away charged particles, atoms, protons, electrons and ions into jets that are so energised they race away from the black hole at almost the speed of light. We can even see one of these jets coming from the black hole in Messier 87.

The level of black hole activity can depend on many factors, such as the mass of the black hole and the amount of gas falling into it. Our Milky Way's supermassive black hole, for instance, is very quiet, with hardly any gas falling into it. Other spiral galaxies have more activity in their centres, with some emitting strong radio waves. However, the most active black holes are called quasars. The closest to us is 600 million light years away, but the majority existed in the universe over 10 billion years ago.

Quasars are fed by gas in two different ways: one is simply clouds of intergalactic gas falling onto a black hole in the centre of a galaxy. These clouds are clumps of gas and dark matter left over from the process of building galaxies over 13 billion years ago. The other way that quasars light up is more exciting – when two galaxies come hurtling towards each other and collide, it causes huge clouds of interstellar gas and stars to fall into their black holes. Sometimes the collision is a hit and run. The gravitational forces of each galaxy tear stars and gas out into long streamers that astronomers call tidal streams. These streams can sometimes be many hundreds of thousands of light years long.

> **"Hubble thought that the elliptical galaxies were the bulges of spiral galaxies without the arms, which he assumed grew later"**



LIGHTHOUSE OF THE COSMOS

Quasars blaze radiation that can be seen from the other side of space

1 The 'calm' black hole

If a black hole is calmly sitting at the centre of its galaxy, it generally distorts the fabric of the universe around it. It leaves a dent in this sheet of space-time from which nothing – not even light – can escape.

2 A swirling disc of dust and gas

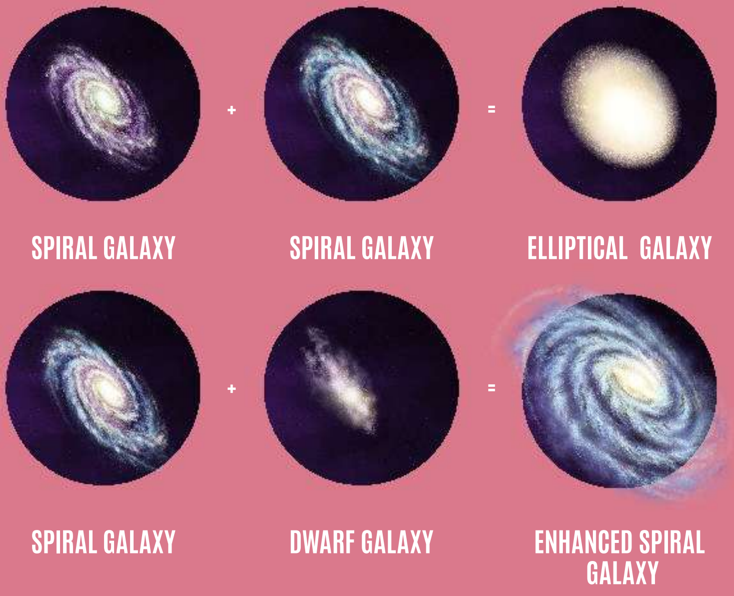
An accretion disc made of gas and dust circles the black hole. If the black hole isn't particularly active, then the matter won't fall into it.

3 Heating up

When the material falls into the black hole and reaches the event horizon – the point of no return – a lot of friction is created, superheating atoms and tearing them apart.

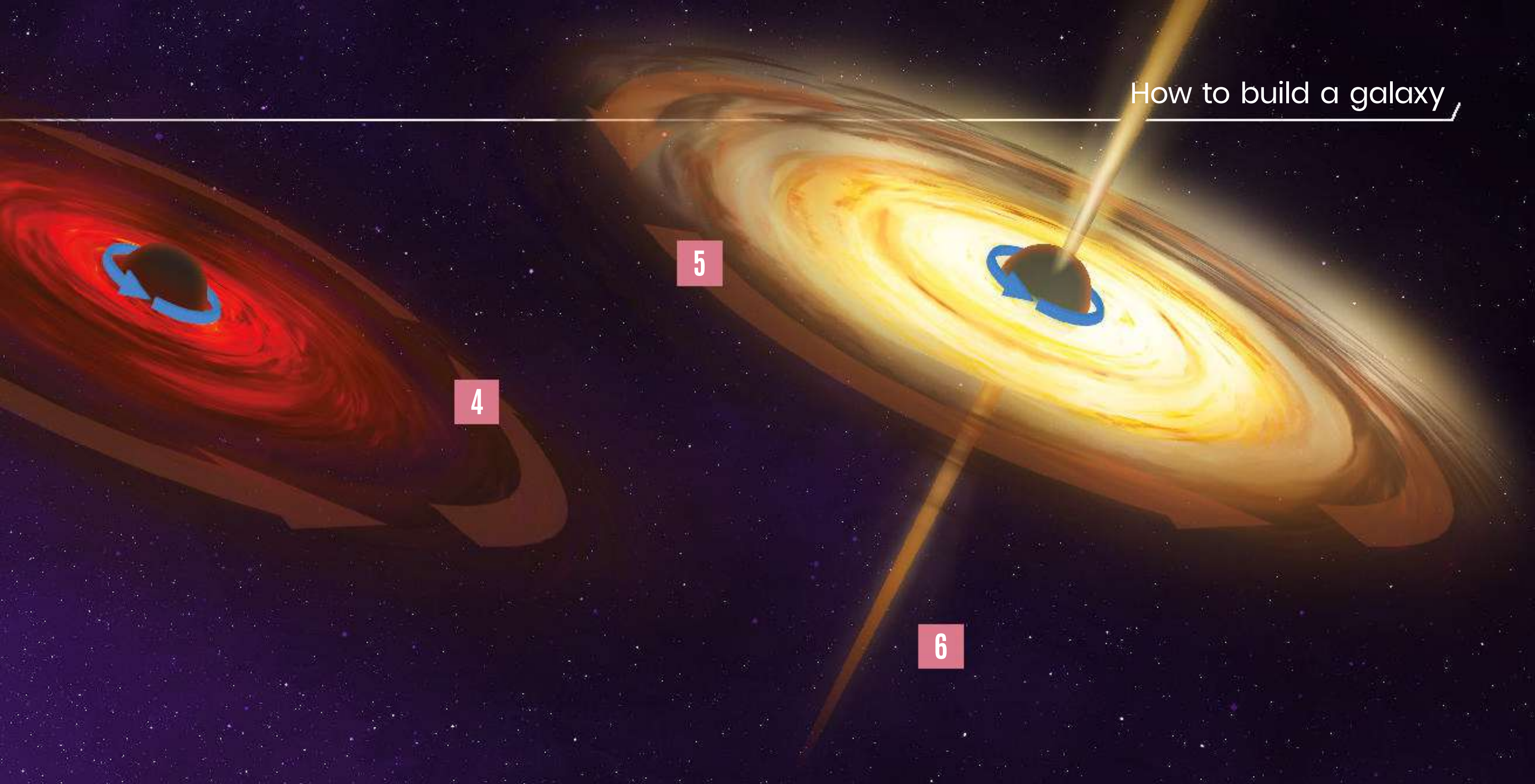
GALACTIC ARITHMETIC

The basic space formulae for creating galaxies



When galaxies collide, it changes the future of the structures involved. Going back in time by 13 billion years, the Hubble Space Telescope is able to see the first galaxies growing by consuming smaller galaxies. This galactic cannibalism continues even today, although at a much slower rate. Even the Milky Way is eating smaller galaxies at this very moment, but they're not going near our black hole, so the centre of our galaxy isn't active. For example, the Canis Major Dwarf Galaxy is only 25,000 light years from Earth and is merging with our galaxy. It contains few stars because the gravity of the Milky Way has stripped most of them away.

Astronomers call such collisions minor mergers. The end result is that the smaller galaxy is swallowed up, increasing the mass of the larger galaxy. At the other end of the scale are the major mergers between two large galaxies of around the same size. When two spiral galaxies collide like this, it destroys their spiral structures and they merge into a giant elliptical galaxy – the opposite of what Hubble's tuning fork suggests. Amazingly, during a galaxy collision stars smashing together is extremely rare because the space between the stars is so large that the chances of two stars coming within each other's gravitational sphere of influence is very small. That means when our Milky Way



4 The active black hole

When a black hole begins spinning into motion, it drags the fabric of space-time, or the universe, with it. This sheet gets twisted up inside the black hole.

5 An active galaxy

Combine the intense magnetic field of the black hole with the ripping of atoms and super-high temperatures and you get an extremely active galaxy. Electrons torn from the atoms find themselves gathered by the magnetic field.

6 Galactic jets

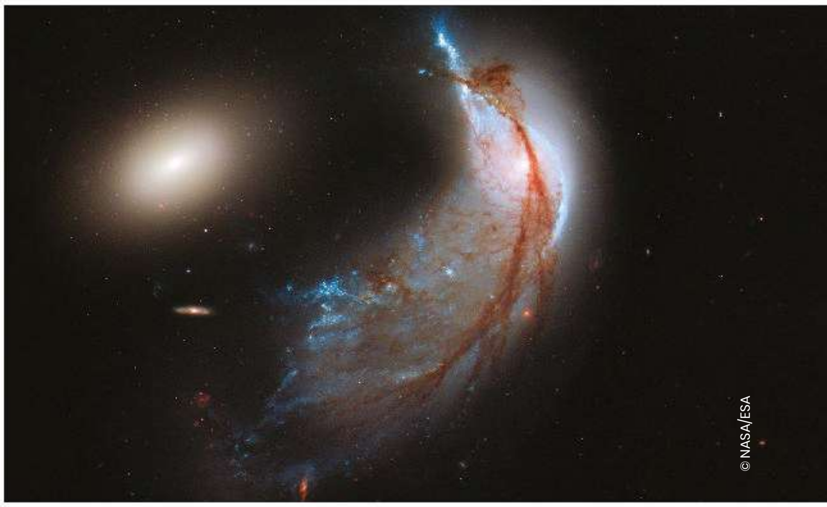
Funnels made by the black hole twisting the fabric of space-time suck up particles. These are accelerated by electric currents before being blasted out into space as focused beams of charged particles and radiation.

undergoes the next phase of its growth and merges with the Andromeda Galaxy in 4 or 5 billion years, our Sun likely won't collide with another star from Andromeda. What will collide will be the huge clouds of interstellar gas that inhabit the spiral arms of both galaxies, igniting in a huge burst of star formation. We call this a starburst, and it can use up all the gas in a galaxy. This is why most elliptical galaxies, which form from mergers, have no star-forming gas left and haven't made any new stars in a very long time. All their short-lived, young stars exploded long ago, leaving ellipticals dusty and red with older, cooler stars.

No galaxies are being made today. All that galactic construction happened over 13 billion years ago, and ever since it has been a case of galactic evolution rather than galactic formation. There are still some crucial pieces of the jigsaw missing, such as whether supermassive black holes formed before the galaxies that exist around them or vice versa, why the disc turns into spiral arms and why these arms do not wind up as they rotate around the centre of the galaxy. Some scientists think that the spiral arms are not actually rigid appendages, but density waves where stars and gas are bunching up. This is a bit like a traffic jam on a motorway, and as soon as some stars hit the brakes and slow down, all the other stars and gas clouds bunch up behind them.

Although some of the pieces are missing, the jigsaw of how galaxies are made, grow and evolve is becoming clearer. We might not be able to see everything, but we can see enough to understand when and where galaxies came from.

Galaxies can merge to form unusual shapes, like Arp 142, which looks like a penguin guarding an egg



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FOCUS ON

VENUS SULPHIDE MYSTERY MAY HAVE BEEN SOLVED

Computational methods can help us understand exotic chemical processes in planetary atmospheres

Reported by Andrew Jones

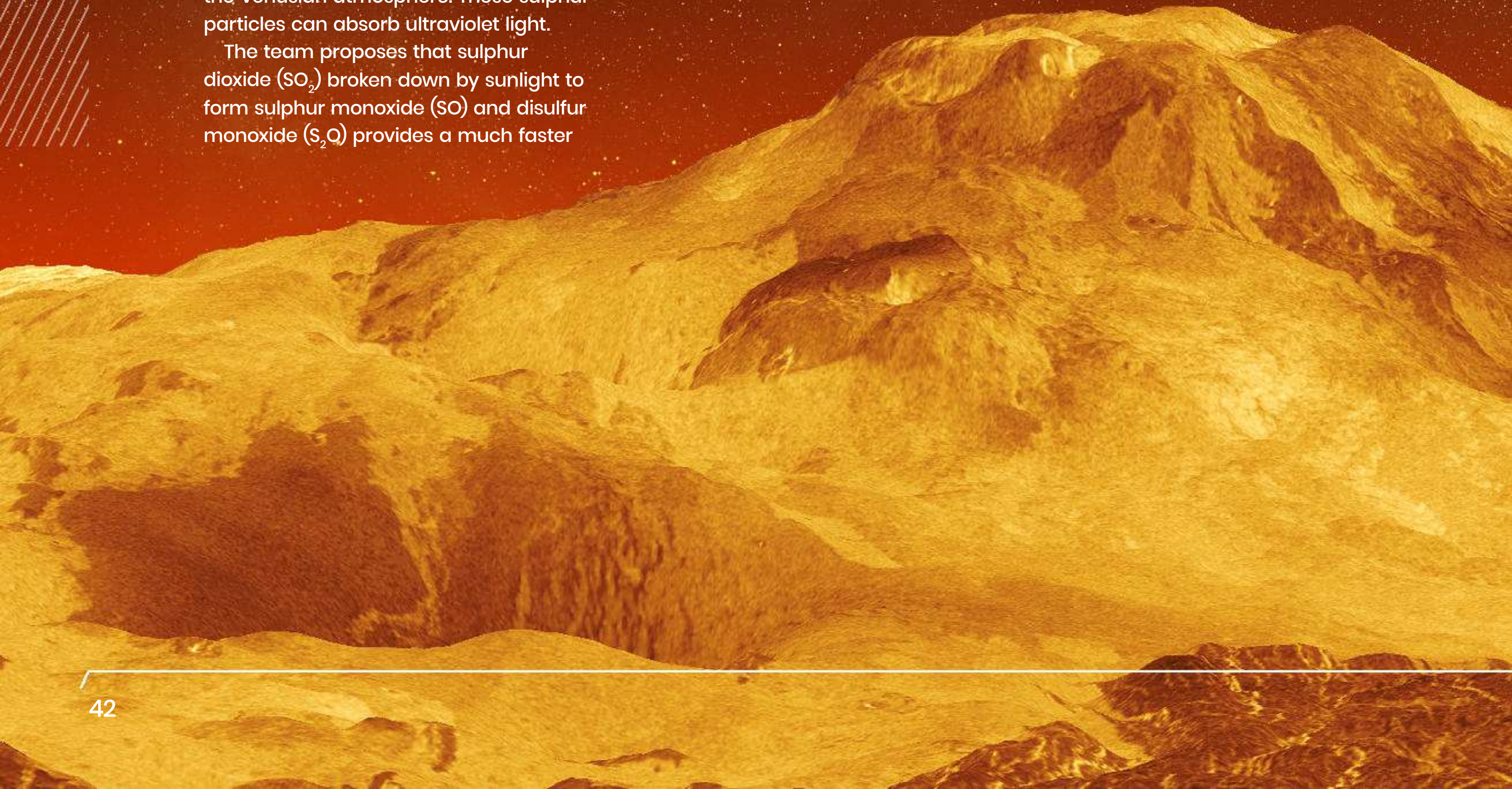
Scientists using new computational methods have come up with a fresh insight into the potential workings of the complex atmosphere of Venus. The planet is shrouded in thick clouds made up mostly of sulphuric acid. These clouds reflect most of the sunlight shining on the planet, making it the brightest object in the sky after the Sun and Moon. However, spacecraft and Earth-based observations have also detected an unknown absorber of ultraviolet light present in the atmosphere.

Following the use of sophisticated computational modelling, a team of scientists now suggests a new pathway for creating disulfur – an allotrope of sulphur consisting of two sulphur atoms – within the clouds of Venus. Disulfur leads to the formation of other sulphur allotropes and subsequently cyclic, or ring-structured, molecules of eight sulphur atoms within the Venusian atmosphere. These sulphur particles can absorb ultraviolet light.

The team proposes that sulphur dioxide (SO_2) broken down by sunlight to form sulphur monoxide (SO) and disulfur monoxide (S_2O) provides a much faster pathway to forming disulfur than the combining of separate sulphur atoms.

Using computational methods is very useful in this context, as working with chemicals and compounds found in the Venusian atmosphere, including sulphur, chlorine and oxygen, can be difficult and sometimes dangerous. "For the first time, we're using computational chemistry techniques to determine which reactions are most important rather than waiting for laboratory measurements to be done or using highly inaccurate estimates of the rate of unstudied reactions," James Lyons, Planetary Science Institute senior scientist and an author of the paper, said. "This is a new and very much needed approach for studying the atmosphere of Venus," Lyons added.

While there's no consensus yet on the identity of the absorber, it's thought to be very likely that sulphur chemistry is involved. Triatomic and tetratomic allotropes of sulphur – the latter also forming from disulfur – have both been proposed to be the mysterious ultraviolet absorber.



THE HIGH LIFE

Sandwiched between freezing and blistering temperatures in a cloud of burning acid, Venusian microbes might have found a way

1 Upper cloud deck

70 to 90 kilometres (43 to 56 miles) above Venus is a region of cold aerosols and sulphuric acid droplets.

2 Lower cloud deck

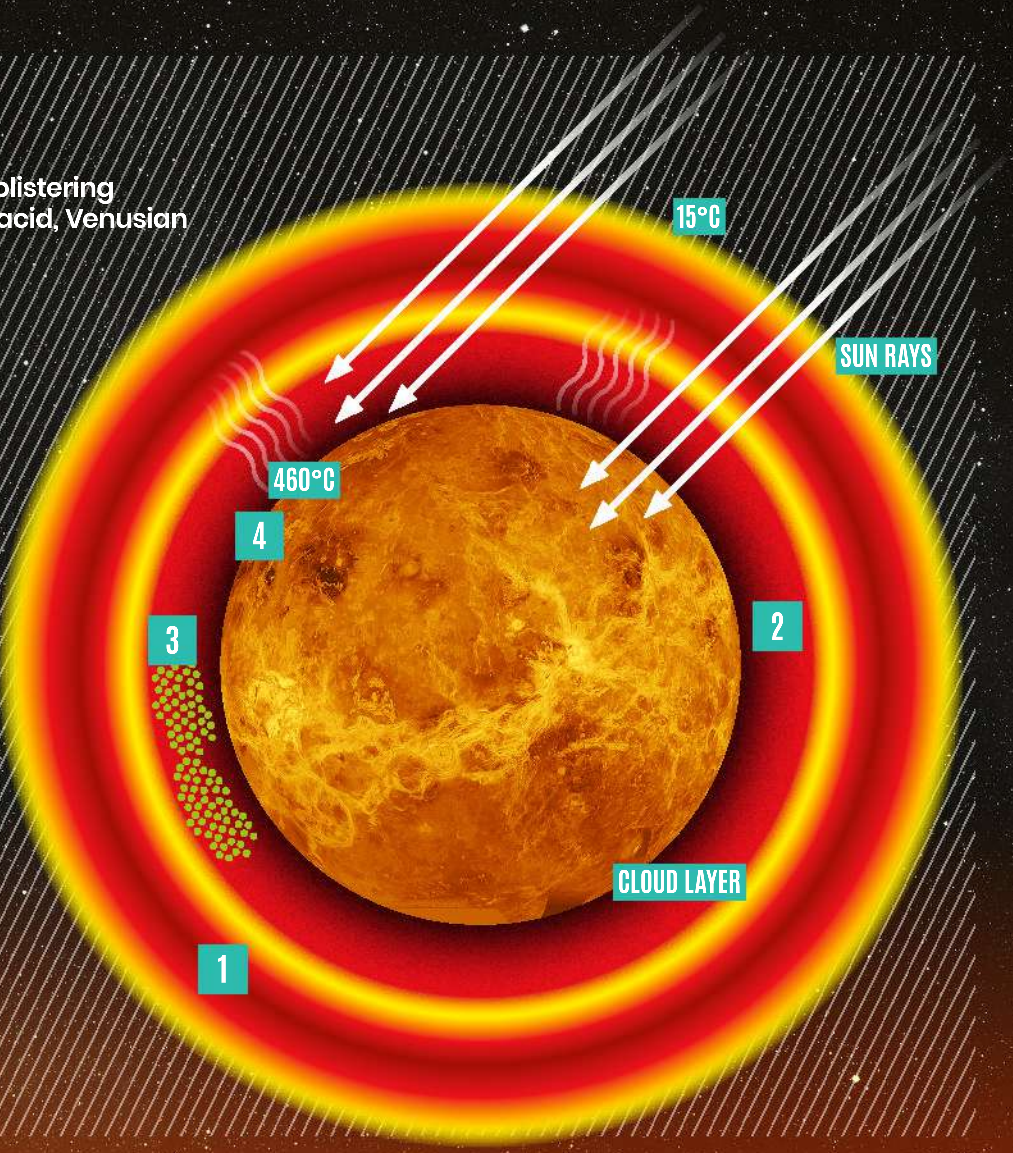
Light carbon dioxide fog from the surface gives way to the base of this cloud layer at around 47 kilometres (29 miles) altitude. 25 per cent of the cloud content is water.

3 Gas of life

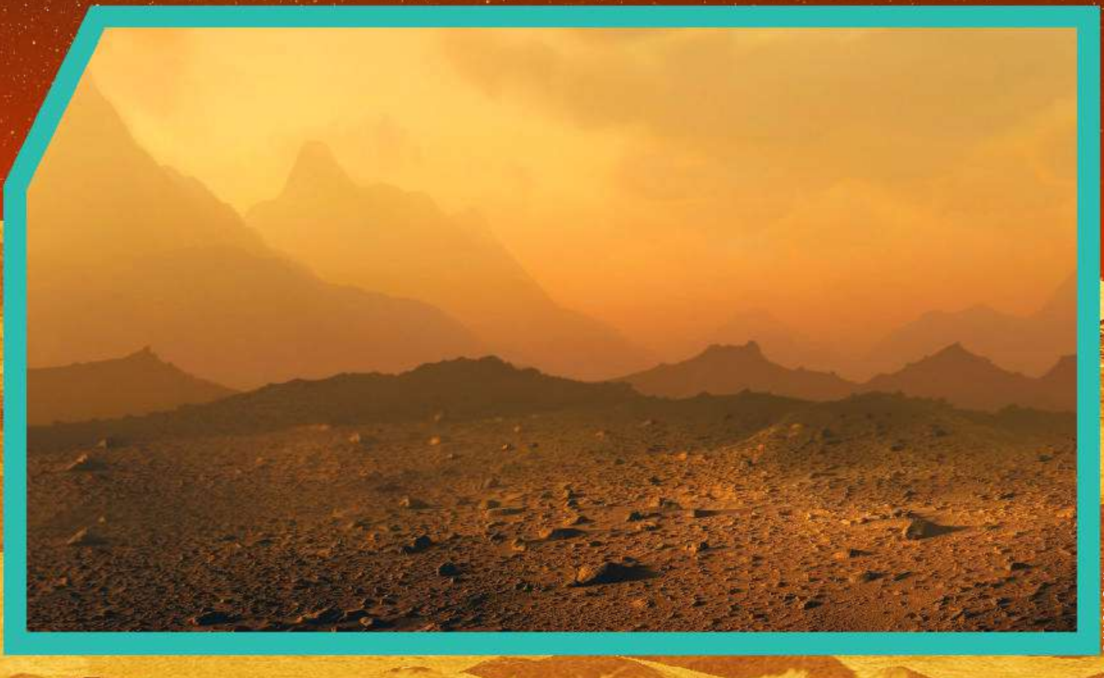
Phosphine gas has been detected around the mid-latitudes of the planet, but the chemistry of the clouds should destroy the gas.

4 Baking heat

Thick clouds trap heat from the Sun's rays, roasting the surface of Venus to temperatures hot enough to melt lead.



Venus has a thick, hazy atmosphere, making surface observations difficult



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10 SPACECRAFT THAT CHANGED THE WORLD

The past, present and future of the world's greatest spacecraft, from the early pioneers to the modern marvels

Written by Nigel Watson

1 APOLLO 11 LUNAR MODULE

The first manned spacecraft to land on the Moon

To perform the first Moon landing, the Apollo 11 mission used two very different spacecraft. The first was the pressurised, conical-shaped Command Module that served as the main living quarters. It was attached to an unpressurised Service Module containing the main rocket engine and propellant.

At launch, the Apollo 11's Command and Service Module (CSM) was mounted above the Lunar Module (LM) on top of the Saturn V rocket. When they moved out of Earth orbit, the CSM separated itself and turned around to attach to the docking port on the LM.

On 20 July 1969 at 20:17 (UTC), Neil Armstrong and Edwin 'Buzz' Aldrin touched down on the Sea of Tranquillity and deployed exploration equipment from a bay on the side of the descent module. On leaving the Moon, the ascent stage's own rocket motor blasted off the descent stage, which remained behind on the Moon. After docking with the CSM, the ascent stage was jettisoned and left to crash back into the Moon. Prior to re-entry the Service Module was jettisoned, and after re-entry the Command Module parachuted down to a splashdown in the sea.

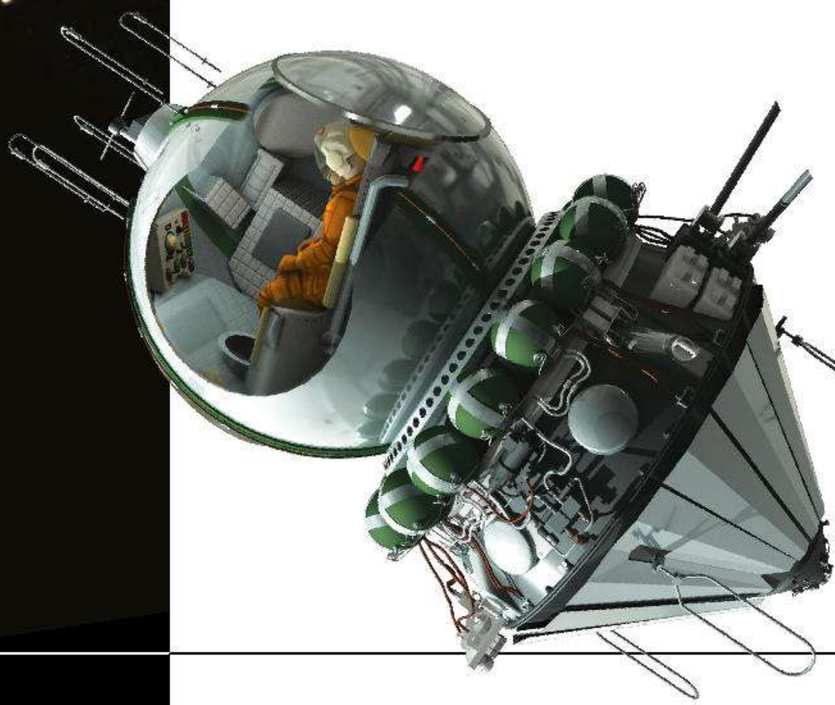
2 SATURN V

A true powerhouse

The mighty three-stage Saturn V rocket towered to a height of 110.6 metres (363 feet) and weighed 3 million kilograms fully fuelled. It was constructed under the direction of Wernher von Braun, the German rocket pioneer, at Marshall Space Flight Center in Huntsville, Alabama. A workforce of 5,000 people took four months to fit the Saturn V's rocket stages together in the Vehicle Assembly Building at Kennedy Space Center in Florida.

Altogether, 15 Saturn V rockets were built. The next closest in size to it was the Soviet Union's N1 Moon rocket that measured 105 metres (344 feet) tall, but it exploded on all four attempts to launch it. In comparison, the Space Shuttle was only 56 metres (184 feet) tall. The Ares I, at 94 metres (308 feet) tall, came close, but it was cancelled due to NASA budget cuts. The soon-to-launch Space Launch System rivals its size at 111.3 metres (365 feet).

> "Vostok 1 was almost entirely autonomous to prevent any human error"



3 VOSTOK 1

The original manned spacecraft

Vostok 1 was the spacecraft that took the first-ever human into space – Yuri Gagarin on 12 April 1961. Although troubled by performance issues, Vostok 1 was a technical marvel. Never before had a vehicle been able to take a human to orbit and return them intact, and therefore Vostok 1 was almost entirely autonomous to prevent any human error. Gagarin could only take control in an emergency, unlike Alan Shepard a few weeks later in the Freedom 7 spacecraft, who had almost full control of his flight.

Although Gagarin spent just an hour and 46 minutes in orbit he – along with Vostok 1 – will forever be remembered for kick-starting the age of human space exploration.

© NASA; Adrian Mann

4

SPUTNIK 1

This pioneering human-made object was the first to go into Earth orbit

On 4 October 1957, the Soviet Union successfully sent the first-ever artificial object into Earth orbit, using an R-7 rocket to get it there. The small, spherical satellite with four pronged legs was named Sputnik 1.

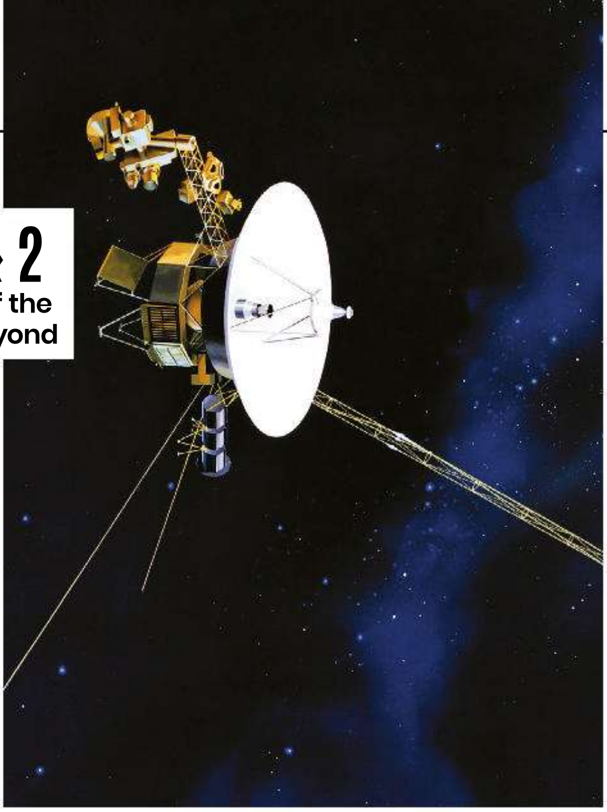
It was a major milestone, not only for the Soviets but also for humanity as a whole, signifying that Earth orbit was both possible and feasible. Sputnik 1 led directly to the Space Race between America and the Soviets. However, it also gleaned some scientific data, such as measuring the electron density in the ionosphere.

It entered an elliptical orbit, reaching over 900 kilometres (560 miles) from the surface of Earth. It transmitted radio signals for 22 days that were monitored around the world and eventually fell back into the atmosphere and burned up on 4 January 1958.

5

VOYAGER 1 & 2

Reaching the edge of the Solar System and beyond



The two unmanned Voyager spacecraft have been on a long journey to escape our Solar System and enter the realms of interstellar space. After achieving the primary mission to explore Jupiter and Saturn, they progressed to explore and image the outer planets and are now studying the outer limits of the Sun's solar wind and magnetic field as part of the Voyager Interstellar Mission (VIM).

They have now both passed through the heliosheath, where the compressed solar wind turbulently interacts with the interstellar medium, and crossed the heliopause, which is considered to be the edge of the Solar System. Both are still sending back data to Earth – the first craft able to give us clues about the interstellar medium that fills space beyond our Sun's influence. Voyager 1 entered interstellar space first on 25 August 2012, with its twin spacecraft following on 5 November 2018 at a distance 122 times the Sun's distance from Earth.

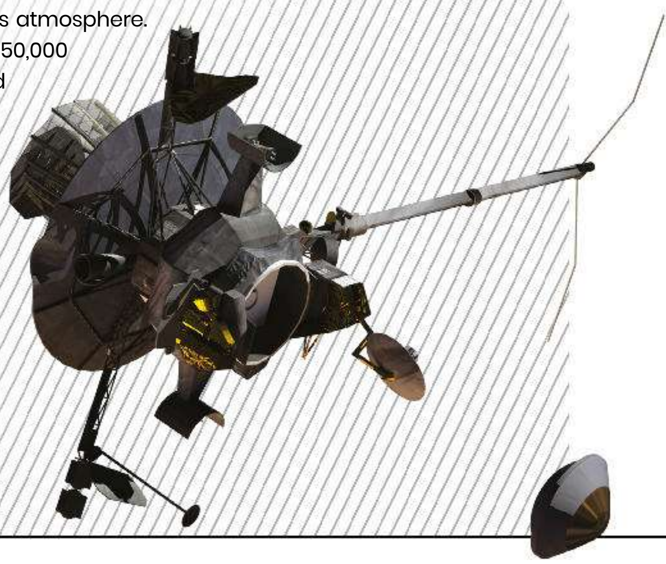
6

GALILEO

The first craft to enter Jupiter's atmosphere

Galileo was taken into space by Space Shuttle Atlantis on 18 October 1989. The unmanned craft consisted of a main orbiting vehicle and a Jupiter atmosphere probe. During its journey, it discovered a huge impact basin on the Moon's far side. It passed within 1,600 kilometres (990 miles) of the Gaspra asteroid, and when passing the Ida asteroid at a distance of 2,400 kilometres (1,500 miles) Galileo's instruments discovered a small moon, Dactyl, orbiting it.

On 8 December 1995, Galileo fired its main engine to become the first human-made object to orbit Jupiter. Galileo made numerous discoveries about the nature of Jupiter's atmosphere. These included finding a radiation belt 50,000 kilometres (31,000 miles) above its cloud layer, strong winds blowing at 600 kilometres (400 miles) per hour and ten per cent less lightning activity than on Earth, though it can be up to a thousand times more powerful. After making 34 orbits of Jupiter, Galileo was nearly empty of fuel, so it was decided to crash the craft into Jupiter. After travelling a total of 4.6 billion kilometres (2.8 billion miles), Galileo disintegrated in Jupiter's dense atmosphere on 21 September 2003.



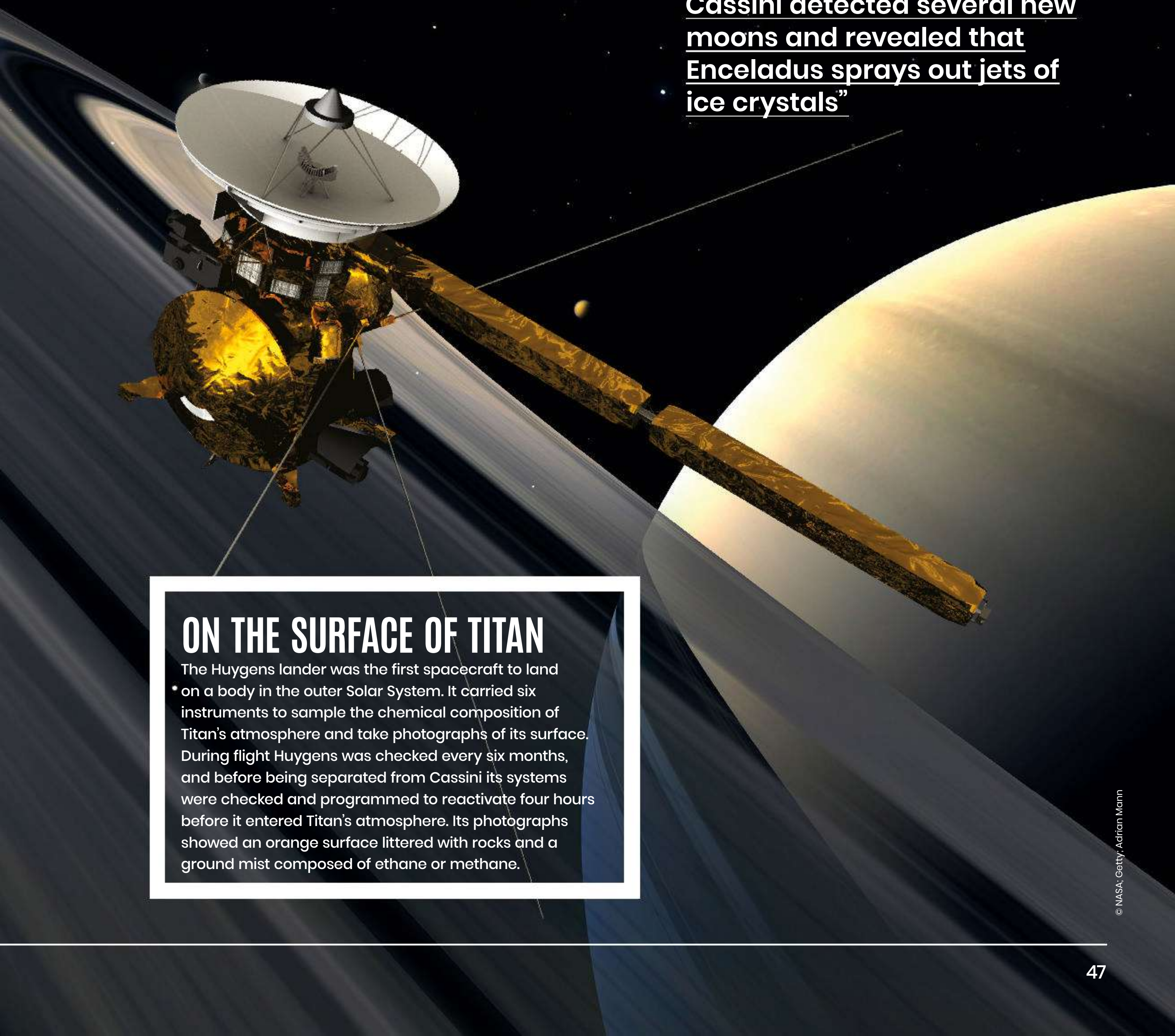
7 CASSINI-HUYGENS

A complex interplanetary probe

At 6.7 metres (22 feet) tall and four metres (13 feet) wide and with a weight of 5,712 kilograms, Cassini is the largest and most complex unmanned interplanetary spacecraft ever launched. Its main objective was to use 12 onboard scientific instruments to conduct a four-year long study of Saturn's atmosphere, surface details, the behaviour of its rings, magnetic environment and the composition of its moons, as well as to carry the Huygens lander to Saturn's moon Titan.

It began orbiting Saturn on 1 July 2004 and completed its prime objectives on 30 June 2008. Early in 2012, it studied the moons of Jarnsaxa and Mundilfari and passed Enceladus. Cassini detected several new moons and revealed that Enceladus sprays out jets of ice crystals that feed into the rings of Saturn. On Saturn, lightning storms and hurricanes were discovered, and on Titan they have found mountains, clouds, snow and liquid methane rivers and lakes under its smoggy atmosphere, much like the conditions on Earth before life evolved here. To end the mission, NASA crashed Cassini into Saturn in 2017.

> "Cassini detected several new moons and revealed that Enceladus sprays out jets of ice crystals"



ON THE SURFACE OF TITAN

The Huygens lander was the first spacecraft to land on a body in the outer Solar System. It carried six instruments to sample the chemical composition of Titan's atmosphere and take photographs of its surface. During flight Huygens was checked every six months, and before being separated from Cassini its systems were checked and programmed to reactivate four hours before it entered Titan's atmosphere. Its photographs showed an orange surface littered with rocks and a ground mist composed of ethane or methane.

© NASA; Getty; Adrian Mann

8 SPACE SHUTTLE

The first reusable manned spacecraft

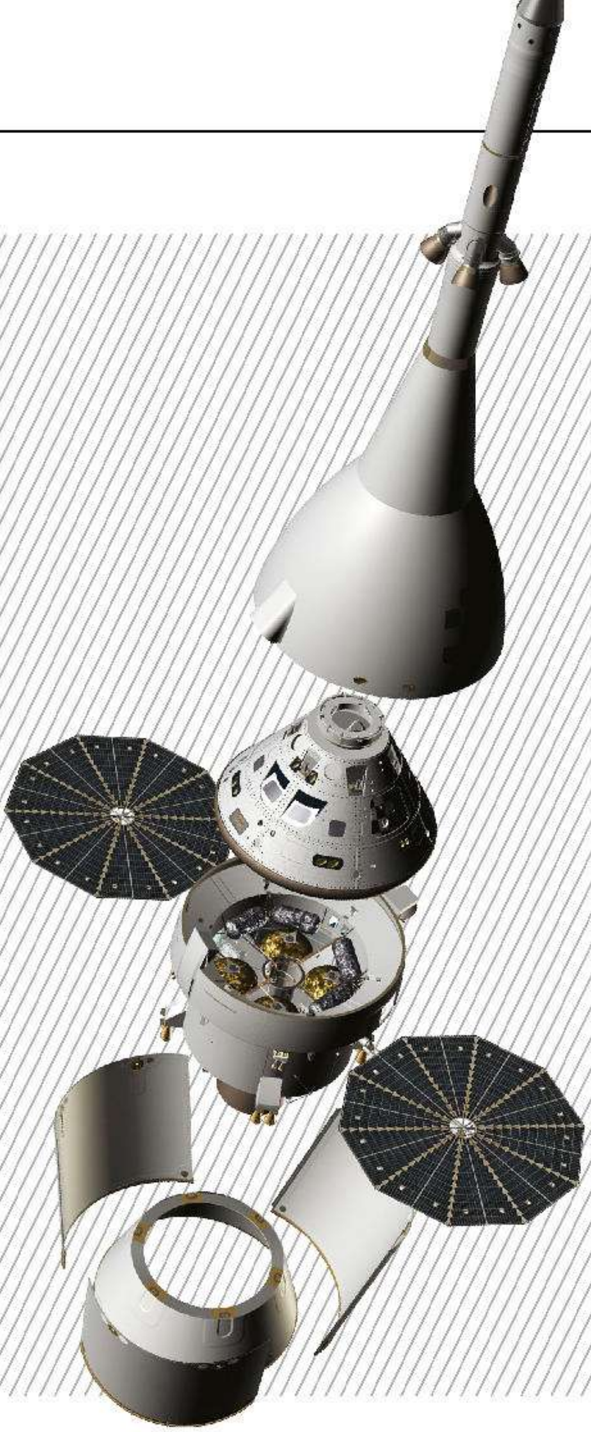
Columbia was the very first Space Shuttle to blast off from the Kennedy Space Center on 12 April 1981. It was mounted on a huge 47-metre (154-foot) long and eight-metre (27-foot) diameter external tank and two solid booster rockets to take it into orbit. The boosters were jettisoned into the Atlantic Ocean where they were recovered and reused, and nine minutes after launch the external tank fell away into the atmosphere and burnt up over the Pacific Ocean. After its mission, the Shuttle 'orbiter' landed on a runway like a conventional aircraft. It could then be refurbished to be launched once more into space.

The flight of Columbia proved that the 2.5 million parts of the Space Transportation System (STS) – as it was officially called – were fully functional. The Shuttle fleet consisted of Columbia, Challenger, Discovery, Endeavour and Atlantis. Atlantis flew the very last mission in July 2011. During this 30-year period, the combined fleet conducted 133 successful missions, made over 21,000 Earth orbits, travelled almost 873 million kilometres (543 million miles) and carried more than 850 astronauts.

Two major disasters struck the Shuttle program. Challenger broke up and exploded during liftoff on 28 January 1986, while Columbia disintegrated during re-entry on 1 February 2003. Nonetheless, the Shuttle craft made many notable achievements, including 37 missions to the International Space Station (ISS). On 25 April 1990, Space Shuttle Discovery deployed the Hubble Space Telescope, the world's first space-based optical telescope. In May 1992, Endeavour, built to replace Challenger, sent three astronauts to recover, repair and re-launch the INTELSAT VI communications satellite. From 1993 to 2009, the Shuttle program made five trips to repair and service Hubble, with Endeavour getting it functioning properly in December 1993.

NASA's concept of the reusable Shuttle as a cost-effective vehicle that could make space travel safe and routine was never fulfilled. In light of this, it was decided to cancel the program after it had assembled the ISS to focus on new space exploration projects.

Atlantis
Atlantis



9 ORION

A new dawn of space exploration

Currently getting ready to ferry astronauts back to the Moon, the Orion spacecraft is world-changing in terms of its advanced design and scale of ambition. Unlike other craft of its kind, Orion has been designed for long-term space missions lasting over six months, which could see the vehicle being used for manned trips to Mars during its service lifetime. It will use a revolutionary abort system that fires the capsule away from danger during the launch and liftoff stages. At its base, Orion has an adaptor unit so that it can be fitted to different launch vehicles.

The craft has a unique life-support system and thermal protection, along with advanced propulsion and navigation systems. When necessary, Orion can send backup crews and cargos to the ISS and can also be used to take astronauts to the Moon, near-Earth asteroids, the moons of Mars and Mars itself.

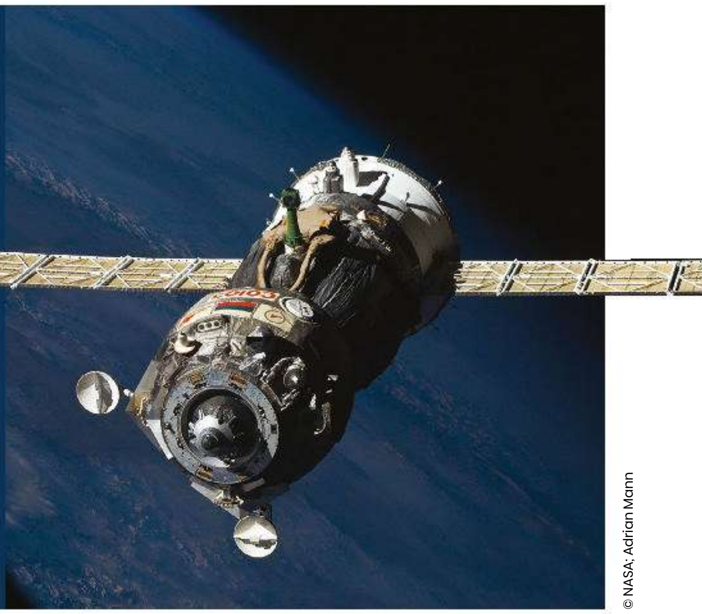
> “Orion has been designed for long-term space missions lasting over six months”

10 SOYUZ

The longest serving manned spacecraft

The Soyuz was designed as an essential part of the mission to land Soviet astronauts on the Moon. A modified two-man version was planned to be the equivalent of the Apollo Command Module, which would release a manned lander to the Moon. After the cancellation of the Moon program, the Soyuz became a manned ferry to the Salyut space station.

The basic craft carries three crew in a spherical orbital module who are returned to Earth in a re-entry module that is positioned behind it. It can automatically dock to a spacecraft, though a manual override can be used when needed. The Soyuz has remained successful due to its modular design and ability to be modernised and modified to adapt to changing mission requirements.



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FOCUS ON

SUPERNOVA WRECKAGE BLASTS OUT COSMIC RAYS

Astronomers tracked cosmic rays to objects that launch particles with energy ten times greater than the Large Hadron Collider

Reported by Robert Lea

Some space radiation crashing into Earth has an explosive origin. Astronomers spotted wreckage from a supernova explosion potentially capable of blasting out high-energy particles – or cosmic rays – that frequently bombard Earth. Their new findings link shock waves and wreckage created by dying stars to natural high-energy proton accelerators in space, dubbed PeVatrons. These intriguing cosmic accelerators – which receive their name from their ability to boost the energies of particles to extreme petaelectronvolt (PeV) levels – have never been conclusively identified.

A handful of suspected PeVatrons were already fingerprinted before this study, including one at the centre of our Milky Way. The research team says their new find of a supernova explosion's leftovers – a cloud of material called G106.3+2.7 – could be the most promising candidate yet. The wreckage lurks 2,600 light years from Earth, possesses a comet shape and has a bright pulsar at one end. Because neutron stars form when stars undergo gravitational collapse, which also launches out supernovae, there's good reason for researchers to think the pulsar and the supernova cloud were created by the same violent event.

Using NASA's Fermi Gamma-ray Space Telescope, astronomers spotted a high-energy gamma-ray afterglow that implies G106.3+2.7 may be capable of blasting out particles at energies equivalent to a million billion electronvolts – ten times as great as generated by the Large Hadron Collider, Earth's most powerful particle accelerator. "Theorists think the highest energy cosmic-ray protons in the Milky Way reach a million billion electronvolts, or PeV energies," Ke Fang, assistant professor at the University of Wisconsin-Madison, said. "The precise nature of their sources, which we call PeVatrons, has been difficult to pin down."

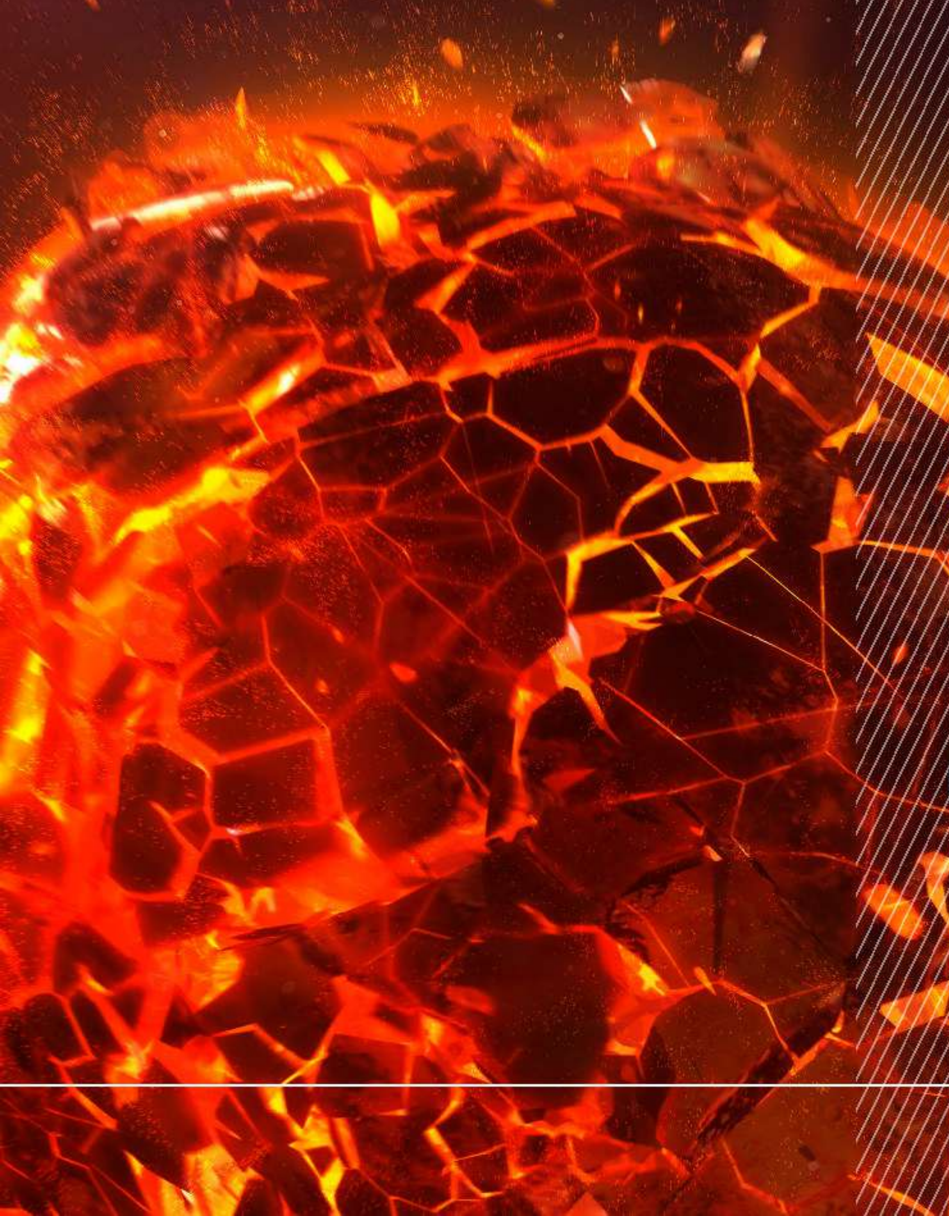
Scientists suspect the supernova wreckage from dead stars accelerates particles to such high energies when charged particles are ensnared by magnetic fields around them. This process allows shock waves from the supernova to buffet the trapped particles repeatedly, increasing their energy each time. Finally, the particles are so energetic that the

> "Theorists think the highest energy cosmic-ray protons in the Milky Way reach a million billion electronvolts, or PeV energies" **Ke Fang**

supernova cannot hold onto them and the particles escape into space as cosmic rays.

Tracing cosmic rays back to supernova wreckage has been difficult because the protons that comprise cosmic rays are electrically charged, so cosmic rays are prone to scattering while interacting with magnetic fields as they journey through space. Astronomers can't easily tell from which direction the rays are coming when they finally reach our planet. But because the acceleration of protons to such high speeds causes the emission of gamma rays, this high-energy light could be a good proxy for detecting the source of cosmic rays.

Both Fermi and the Very Energetic Radiation Imaging Telescope Array System (VERITAS) detected gamma rays from inside the tail of G106.3+2.7. Other observatories have found extremely high-energy photons coming from the same area, indicating this could indeed be a PeVatron. "This object has been a source of considerable interest for a while now, but to crown it as a PeVatron we had to prove it's accelerating protons," researcher Henrike Fleischhack of NASA's Goddard Space Flight Center in Greenbelt, Maryland, said. "The catch is that electrons accelerated to a few hundred TeV can produce the same emission. Now, with the help of 12 years of Fermi data, we think we've made the case that G106.3+2.7 is indeed a PeVatron."



HOW DO STARS EXPLODE?

Stunning supernova explosions can come from very different stellar systems

1 Matter transfer

Two stars can orbit close enough to each other that matter will transfer from the companion onto a white dwarf star in a process called accretion.

2 Finding the right stars

These occur when a white dwarf, like the one our Sun will leave behind after its death, is found in a binary pair with another star.

3 Squeezing down

This accretion of matter adds extra mass. The additional gravitational forces compress the already highly pressurised core of the white dwarf.

4 A star reborn

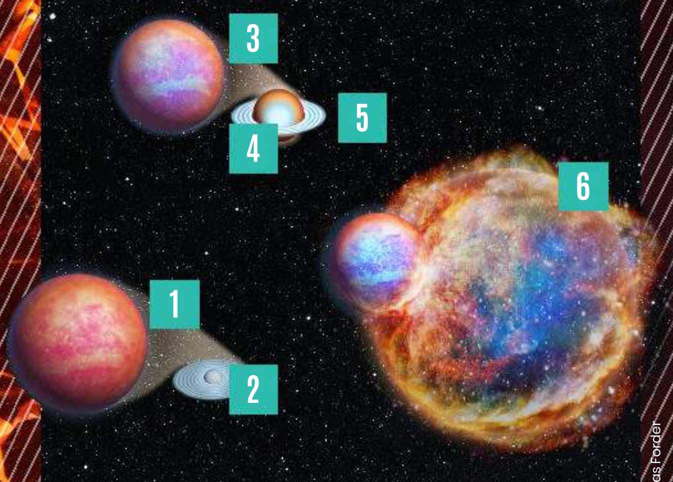
As the star approaches the Chandrasekhar limit, the dying star comes to life again and undergoes fusion in its centre.

5 Limited gains

White dwarfs can only get so massive through accretion. The Chandrasekhar limit puts their maximum size at about 1.4 times the mass of our Sun.

6 Outward pressure

This time the star cannot expand to accommodate the outward pressure of its newly kindled fusion burning. Instead expansive forces build, creating a violent supernova.



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MOON PROFILE

EUROPA

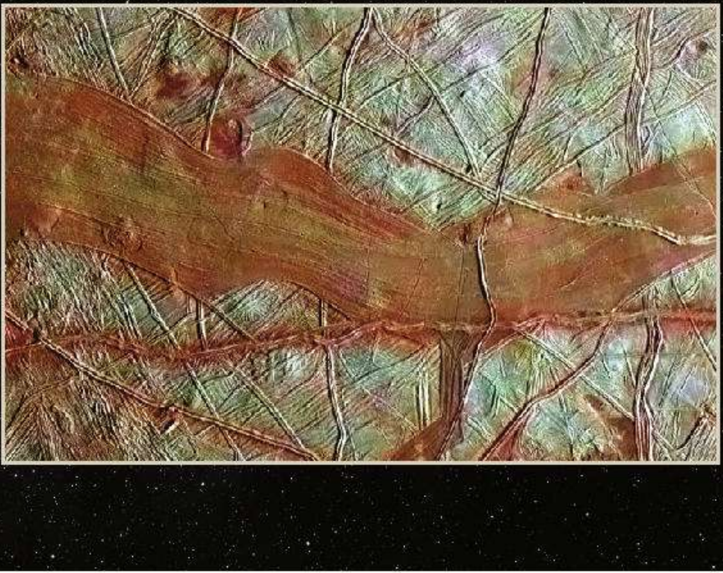
One of the Solar System's famous ocean worlds is an exciting prospect for further exploration

Europa is one of the four Galilean moons that orbit the Solar System's largest planet, Jupiter, discovered in 1610 by Italian astronomer Galileo Galilei. Underneath its icy, scarred surface could lie a salty ocean – just like those that make up 71 per cent of Earth's surface. Europa is tidally locked to Jupiter, meaning the same face of the moon is pointing at the Jovian giant at all times, much like the Moon and Earth. Europa has an equatorial diameter of 3,100 kilometres (1,940 miles), which is 90 per cent of the Moon's diameter. If you were to replace the Moon with Europa in our sky, to the naked eye they would both seem about the same size. However, Europa would be much brighter on account of its surface ice reflecting 5.5 times more sunlight than the Moon, giving it a higher albedo.

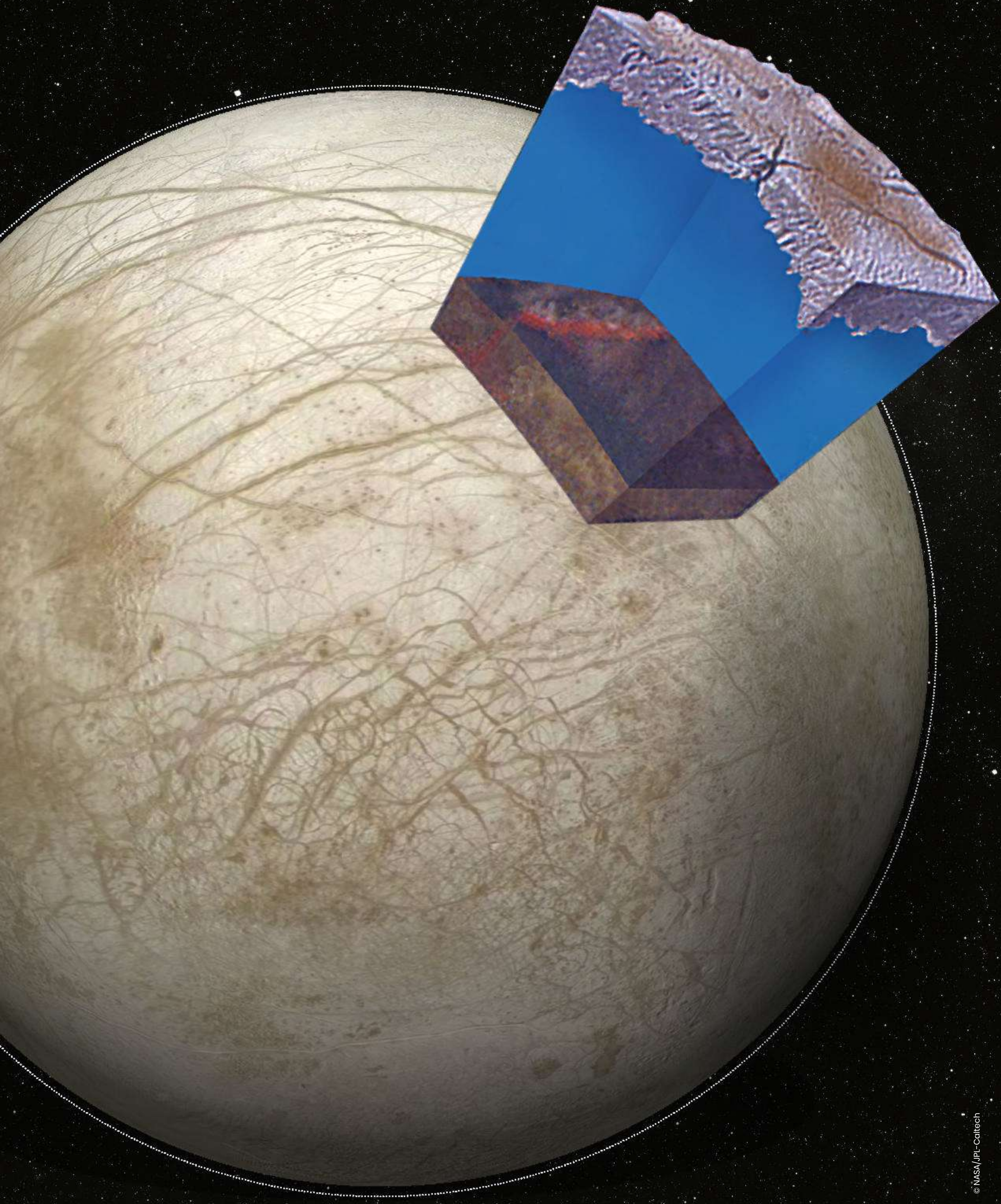
The process behind the creation of Jupiter's largest moons is still hotly debated, but astronomers largely agree that they formed from leftover debris from the formation of Jupiter roughly 4.5 billion years ago. Fast-forward to today and Europa is a water-ice ball with fractures criss-crossing all over the surface. The number of craters currently found across its cracked terrain indicate that the moon is no older than 90 million years old, suggesting there is likely to be some form of surface replenishment that also brings salts and sulphur compounds to the outer layer. Surrounding the icy world is a thin atmosphere composed of molecular oxygen.

The core is most likely made of iron, surrounded by a tough, rocky mantle. In between that and the icy crust is a suspected body of liquid. Some may wonder how such a small world, so far away from the heat of the Sun, can maintain an ocean of salty water similar to Earth's. It's likely due to the grand gravitational effects of Jupiter pulling and pushing the insides of Europa, causing it to heat up and in turn transforming its ice into water. This process is known as 'tidal heating', and it can be observed happening with grander effects on fellow moon Io – its interior is heated up to such an extent that volcanoes litter the surface.

This tidal heating is what maintains the ocean and provides the energy to replenish the surface via the outburst of plumes or a form of icy plate tectonics. Ever since astronomers became aware of the vitalising interior of Europa, they have pieced together that it has the fundamental building blocks for life to exist: liquid water, chemical compounds for consumption and an energy source. For this reason especially, planetary scientists are excited to return to the Galilean moon. There is a high chance that life could exist in this part of the Solar System, even if it's just in the form of simple microbes in the liquid oceans.



This shows almost-pure water ice, shown in white, broken up by contaminated water ice, shown in red



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NEWS FROM EUROPA

Table salt on the surface

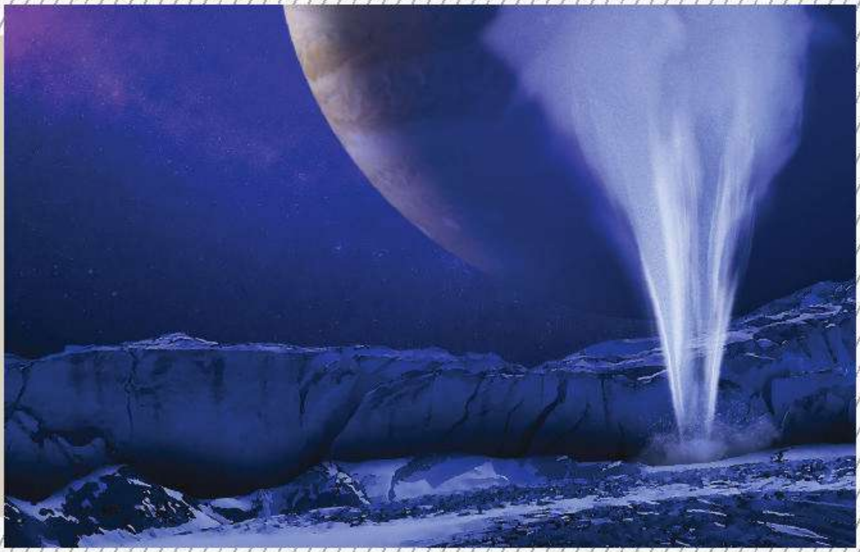
Europa has had visitors, notably NASA's Voyager and Galileo. On their flybys of the moon, analyses showed that the icy crust consisted of water ice and a substance originally thought to be magnesium sulphate. After revisiting the surface using the W. M. Keck Observatory based in Hawaii and Hubble, astronomers now know that it wasn't magnesium sulphate and is actually sodium chloride – more commonly known as table salt. It was laboratory tests by Kevin Hand at NASA's Jet Propulsion Laboratory that revealed that irradiated ocean salts under Europa-like conditions exhibit distinct features and a yellowish colour – table salt exhibits this colour on the surface of Europa, confirming its presence.

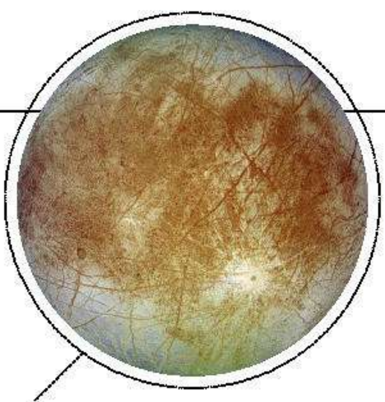
Setbacks for the next explorer

Unfortunately, the Europa Clipper mission, an orbiter that will spend about three years at the moon, and the proposed Europa Lander mission have come under scrutiny after a nine-month investigation concluded that there are serious issues that need to be addressed in order to satisfy both NASA and US Congress. After finding these conflicts of interest and issues in the budget, the investigation team concluded that ten changes must be made to get the project back on track, including altering the overall staffing regime, rescheduling milestones and making sure that any estimates be made in accordance with other projects. With these changes, it's hoped the 2024 launch of Europa Clipper can go ahead.

Struggling to find plumes

Europa shares similarities with Saturn's moon Enceladus: both exhibit signs of a subsurface ocean that could potentially harbour life. One major difference, however, is that Enceladus has been studied much more thoroughly, courtesy of NASA's Cassini. In its close-up analysis, Cassini detected plumes of material emerging from the surface of Enceladus, along with a distinct temperature spike in the data to match. However, this doesn't appear to be the same for Europa, suggesting that either Europa plumes are very different, the plumes are only occasional, that they don't exist or that their thermal signature is too small to have been detected by current data.





EUROPA FACTS

Europa is the smoothest object in the Solar System, lacking craters and mountains

The cracks on the surface are likely from the constant movement of the sea when it gets too close to Jupiter

671,100

Europa orbits Jupiter at a distance of 671,100 kilometres (417,000 miles) – almost double the Earth-Moon distance

Europa is stuck in an orbital resonance with two fellow Galilean moons; for every orbit Ganymede completes, Europa makes two and Io completes four

-160°C

Europa's surface temperature at the equator never reaches higher than -160 degrees Celsius (-260 degrees Fahrenheit)

All of Jupiter's moons are named after lovers of Zeus from Greek mythology; Europa was the queen of Crete

NASA TIMELINE OF EUROPA VISITORS

Date: 3 December 1973
Spacecraft: Pioneer 10

Date: 3 December 1974
Spacecraft: Pioneer 11

Date: 5 March 1979
Spacecraft: Voyager 1

Date: 9 July 1979
Spacecraft: Voyager 2

Date: 8 December 1995 to 21 September 2003
Spacecraft: Galileo

Date: 28 February 2007
Spacecraft: New Horizons

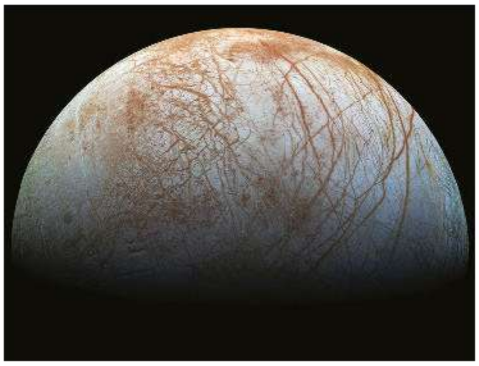
Date: September 2022
Spacecraft: Juno

> "Tidal heating is what maintains the ocean and provides the energy to replenish the surface"

PAST AND FUTURE EXPLORATION

Although Europa hasn't had the same close inspection as Enceladus, many spacecraft have made a flying visit of the moon as they use Jupiter's enormous mass to provide a gravity assist, using the planet's mass to slingshot to a faster speed. These visits began with NASA's Pioneer 10 and 11 in 1973 and 1974 respectively. Afterwards came the two Voyager spacecraft in 1979, sending back pictures of Europa's icy surface in stunning resolution. This began speculation that the moon had a subsurface ocean, gathering traction when NASA's Galileo spent eight years at the Jovian system. This long-duration study revealed a host of exciting new discoveries about Europa and its fellow moons.

The future is very exciting for the exploration of the Galilean moons. Two major space exploration organisations – the European Space Agency (ESA) and NASA – are looking to visit. Due to launch in June 2023 is the ESA's JUpiter ICy moons Explorer (JUICE), which will head to the system in order to study Ganymede, Callisto and Europa. The following year – at least assuming there are no further delays – NASA will launch its Europa Clipper, solely focused on studying Europa. After much discussion, the Europa Clipper team decided that due to Jupiter's radiation it would be best to put the orbiter in an elliptical orbit that makes 45 close flybys over the course of roughly three years. Proposed as a separate mission launching around 2027 is a Europa Lander that will complement the Europa Clipper mission.



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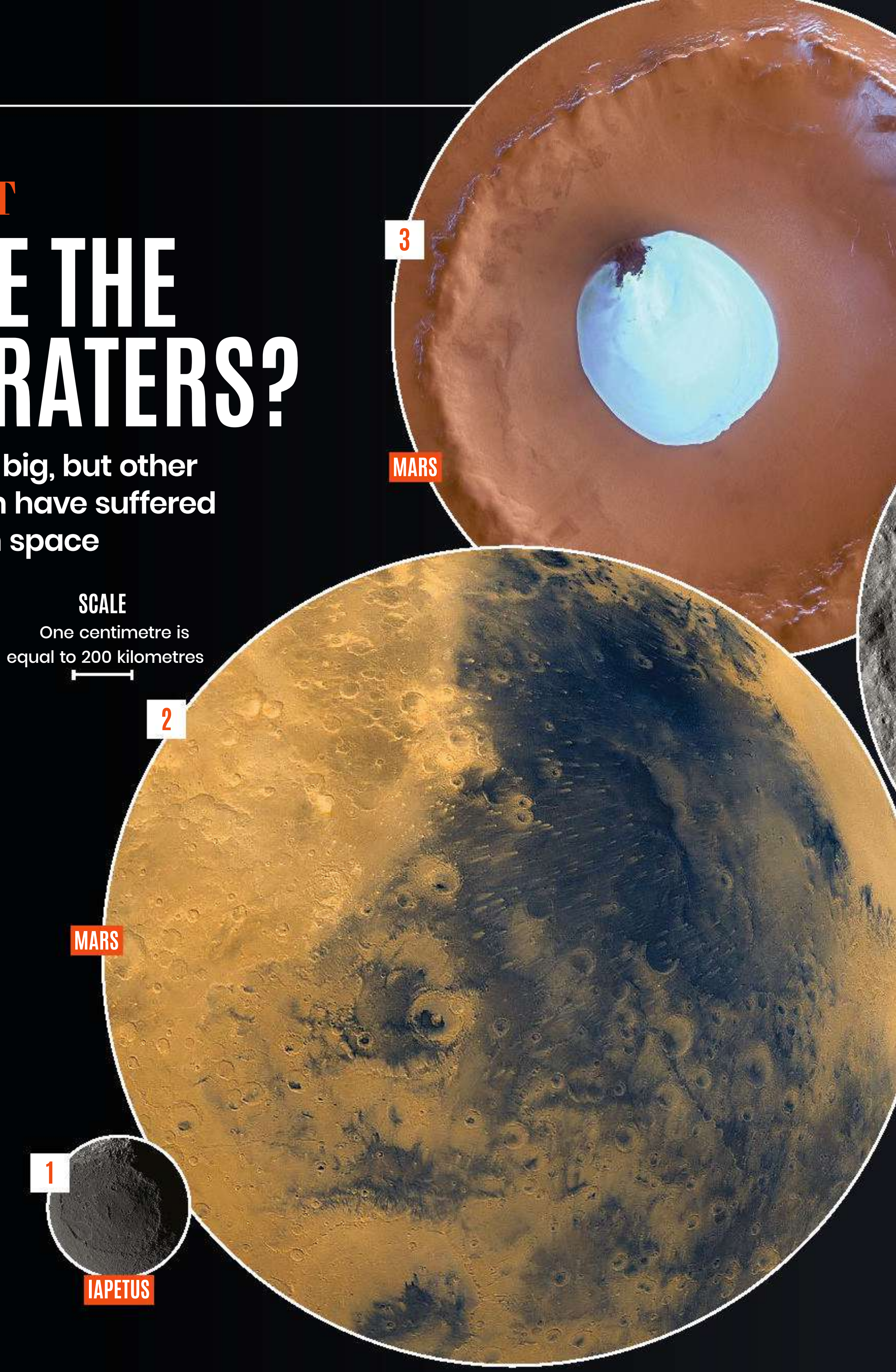
INSTANT EXPERT

WHERE ARE THE BIGGEST CRATERS?

Earth's largest craters are big, but other worlds in our Solar System have suffered even bigger impacts from space

The largest confirmed crater in the Solar System is the one that lies beneath Utopia Planitia, a huge plain in the northern hemisphere of Mars. With a diameter of 3,300 kilometres (2,050 miles), this huge and shallow basin must have been created by the force of a wide impactor and would have had a devastating effect on Mars at the time. But the Utopia impact happened roughly 4 billion years ago, and later geological activity has done a lot to hide it. The basin was only confirmed in 2001 using satellite maps of Martian topography. Far more easily identified as an impact basin is Hellas Planitia, an oval depression in the Red Planet's southern hemisphere some 2,300 kilometres (1,429 miles) across. What's more, these same maps revealed that a vast swathe of the northern hemisphere of Mars, around 10,600 kilometres (6,587 miles) across at its widest, is notably depressed and flat compared to the rest of the planet. Some geologists have suggested that the entire north polar basin is also an impact structure – if confirmed, it would dwarf anything else in the Solar System.

Impact craters in the outer Solar System tend to be significantly smaller, with the largest only a few hundred kilometres across. This may be partly because the impacts that bombarded the larger asteroids and moons were genuinely less powerful, but it's also for the simple reason that smaller objects can only withstand lesser impacts without shattering apart completely. The asteroid Vesta, for example, is misshapen by the vast Rheasilvia crater, whose diameter of 505 kilometres (314 miles) is a full 90 per cent of Vesta's ideal spherical size. Several of Saturn's icy moons display craters with 30 to 40 per cent of their diameter, and their creation must have come close to breaking them up.



SCALE

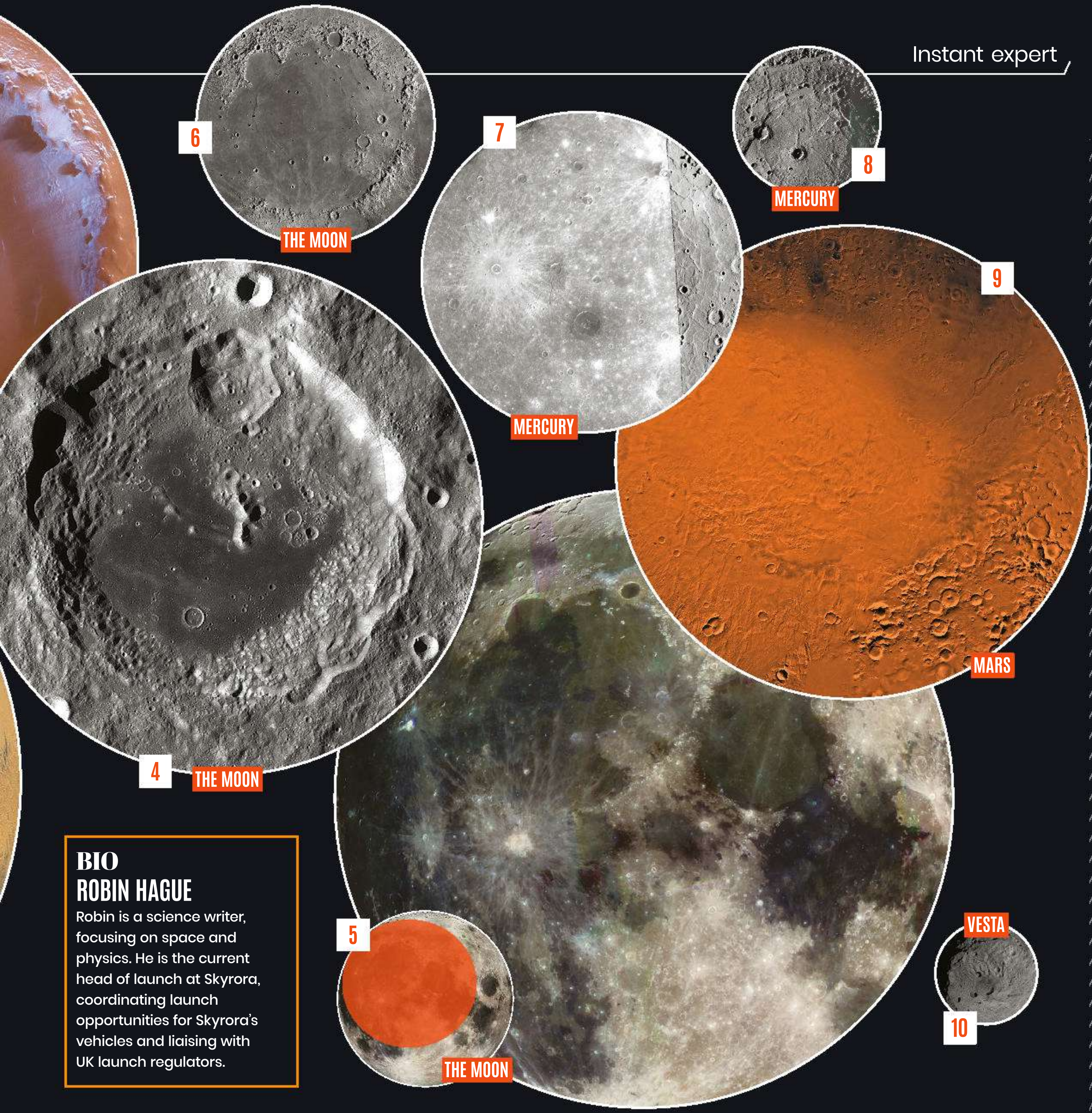
One centimetre is equal to 200 kilometres

1 Turgis The largest impact crater in the outer Solar System lies on Saturn's icy moon Iapetus. At 580 kilometres (360 miles) across, its diameter is 40 per cent that of Iapetus itself.

2 Utopia Planitia The largest confirmed impact basin on Mars creates a huge bay on the edge of the southern highland terrain and contains the landing site of NASA's Viking 2.

3 Mars' north polar basin What might be the Solar System's largest impact basin creates a huge elliptical depression around the Martian north pole that's partially obscured by volcanic rises.

4 South Pole-Aitken basin This vast crater on the lunar far side extends down to our satellite's south pole. Despite its size, it has never been flooded with volcanic lava, so it retains its original depth.



BIO
ROBIN HAGUE

Robin is a science writer, focusing on space and physics. He is the current head of launch at Skyrora, coordinating launch opportunities for Skyrora's vehicles and liaising with UK launch regulators.

5 Procellarum basin

This enormous suspected basin is filled by Oceanus Procellarum, a lunar ocean that dominates the Moon's western hemisphere as seen from Earth.

6 Imbrium basin

The Imbrium basin is the second-largest lunar impact crater and the only one to have been precisely dated. Rock samples suggest it formed nearly 4 billion years ago.

7 Caloris basin

Mercury's biggest crater. Shock waves from its formation spread either side of the planet, creating a jumble of chaotic terrain where they met up again on the far side of Mercury.

8 Rembrandt

This sharply defined basin is the second largest on Mercury. It's roughly 3.9 billion years old and was discovered by NASA's MESSENGER probe during a 2008 flyby.

9 Hellas Planitia

Mars' most obvious impact crater, the Hellas basin is a deep depression in the planet's southern highlands. Red dust blown from around the planet accumulates here.

10 Rheasilvia

This enormous dent in the south pole of Vesta changes the shape of the entire asteroid. Rheasilvia is the largest impact crater relative to its parent body in the entire Solar System.

© NASA; ESA

SPACE VOLCANOES

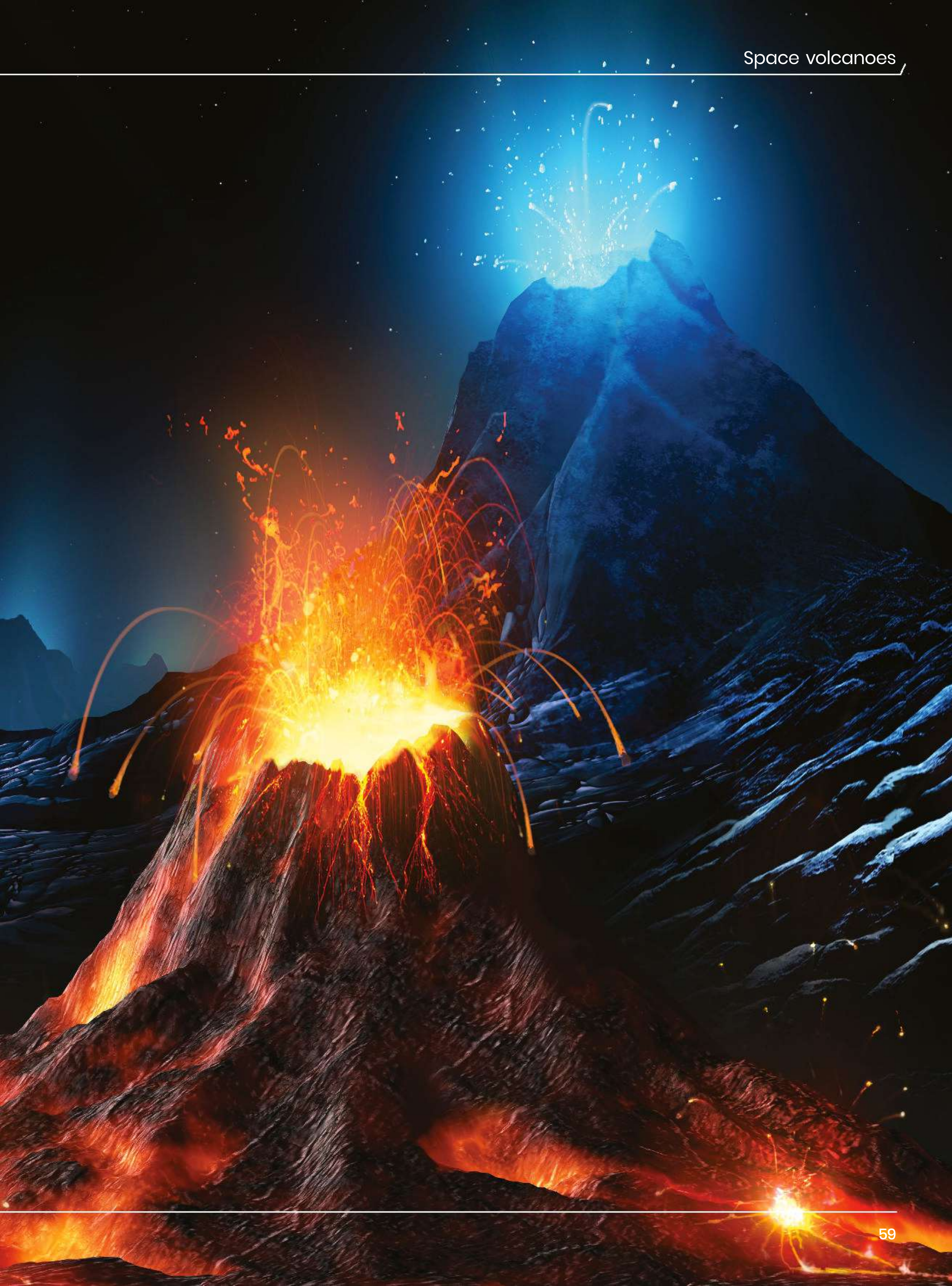
From Venus to Mars and the moons around far-flung planets, volcanoes have helped shape the bodies of our Solar System

Written by David Crookes

On 5 March 1979, Voyager 1 made its closest approach to Jupiter. What it discovered astounded navigators at the Jet Propulsion Laboratory in California. Not least of all astronomer Linda Morabito, who had been analysing an image taken by the spacecraft and saw a puzzling feature that turned out to be a volcanic plume off the limb of Io. It was 270 kilometres (170 miles) tall, spewing sulphur into the airless sky with great ferocity. This volcano came to be known as Pele, after the Hawaiian fire goddess, and its discovery was hugely significant: it was the first time that an erupting volcano had been found anywhere other than Earth.

It wasn't the first time that alien volcanoes had caught the imagination. Missions to the Moon had uncovered basalt samples some 3.3 billion years old, and Apollo 15 landed close to Hadley Rille, an immense groove on the Moon 1.5 kilometres (0.9 miles) wide and 300 metres (984 feet) deep. This groove likely originated as a lava tube whose roof collapsed. The unmanned Mariner 9 highlighted a varied Martian terrain in 1977 which had huge volcanoes, including the mammoth Olympic Mons. Yet these discoveries were all completely extinct.

Io proved to be a swirl of colours thanks to a thin atmosphere laden with sulphur, and was showing signs of being the most geologically active body in the Solar



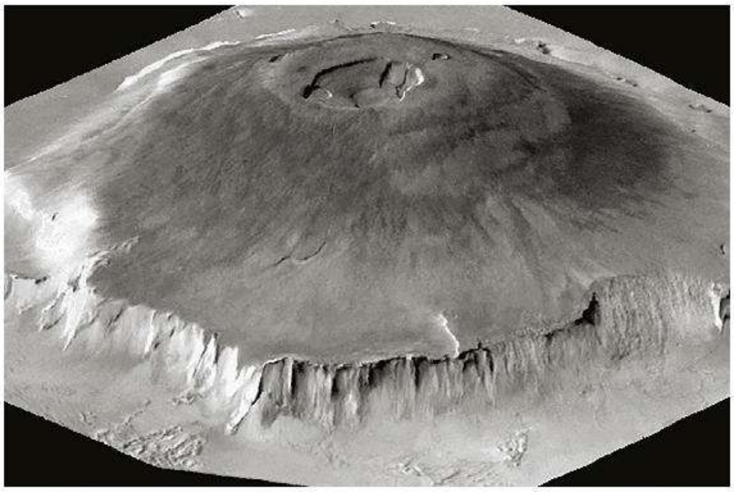
System: more than 150 active volcanoes – of more than 400 in total – have been discovered there. Moons Enceladus and Triton also have active volcanoes. Venus, too, as well as the Jovian moon Europa. "Although we have volcanoes on Earth, you have to study somewhere different to understand the big picture," says Dr Rosaly Lopes of NASA's Jet Propulsion Laboratory.

Lopes became interested in volcanology during her studies, becoming particularly hooked when Mount Etna exploded and her volcanology professor didn't show up. "I thought it was really exciting to work on something where you had to rush off like that," she says. Following her graduation she worked on Galileo, a mission to Jupiter that launched in 1989. She studied infrared data from Io that allowed her to detect the heat from the volcanoes. Between 1996 and 2001 she discovered 71 active volcanoes – more active volcanoes than anyone else. "Io has sulphur dioxide pretty much everywhere," Lopes explains. "So you have to detect either the heat, plume or a surface change to show that a volcano is active. The easiest way is to detect heat, so I would compare pixels of the images we received, looking for infrared hotspots that were different to the surroundings. We had limits of resolution and it was a lot of work, but it wasn't that hard."

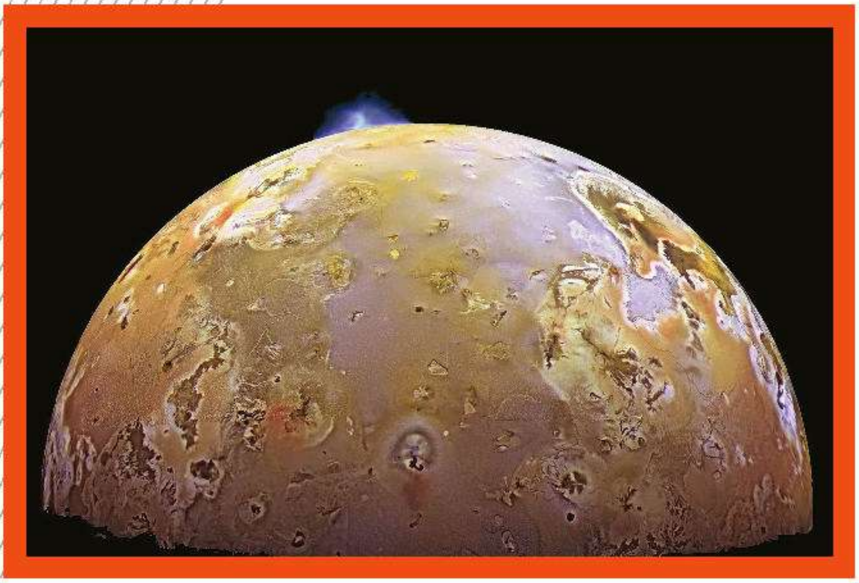
There are different types of volcanoes in the Solar System. Shield volcanoes are built up of fluid lava flows and they have broad, low-profile features. Composite volcanoes are conical, built up of ash, rock, dust and hot steam. Depending on their location in space, they either spew molten silicate rock magma or – as is the case beyond Mars – cold or frozen gases including water, ammonia or methane. Volcanic activity can be short or long-lived, continuing to spew for decades at a time. Io volcanoes stay active for very long periods of time. "They are much more powerful than the volcanoes on Earth," says Lopes. "When Voyager 1 flew past in 1979, about a dozen volcanoes were active. When Galileo visited, most of these volcanoes were still active and there were detections from the ground in-between. The New Horizons voyage to Pluto used Jupiter as a gravity assist. We did some observations of Io at that time, and some of the very same volcanoes were still active."

"There are some volcanoes on Earth that are always active on land. There are also volcanoes under the ocean that are harder to find. Certainly Io's volcanoes have the largest heat output and the largest calderas – craters formed by volcanic eruptions or the collapse of surface rock into a vacant magma chamber. Io is considered to be one of the most volcanically active bodies that we know of." The most unusual volcano on Io is Loki Patera. It's the most powerful and has the largest volcanic caldera in the Solar System. There is also potential evidence of a lava lake, usually a rare occurrence, but seemingly common on Io. "We want to know what is creating these lava lakes and how the eruption mechanisms work," says Lopes. "Loki Patera has some peculiar patterns – an almost cyclical pattern of eruptions that we thought we understood, but then stopped."

How explosive a volcano is depends on its composition and the amount of gases dissolved in the magma. It's often been compared to shaking up a fizzy drink and opening it – if the drink has been allowed to go flat, it's likely to come out with less ferocity than one with its full soda potential. "In a volcano, you get these gases that are dissolved in the magma," says Lopes. "When magma rises towards the surface, the pressure lessens and the gases want to come out. If the lava is very viscous, or sticky, the gases cannot escape easily and eventually they will come out explosively. You can get what we call a Hawaiian-type eruption where you may have this beautiful lava oozing in fountains."



Olympus Mons is the biggest peak in the Solar System



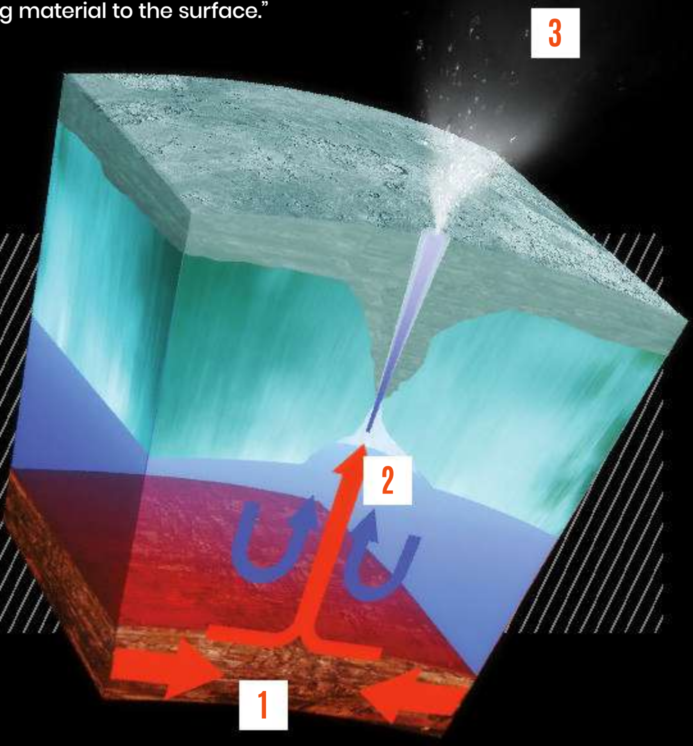
Io's volcanoes are very different to Earth's

VOLCANOES OF FIRE AND ICE

Volcanoes can blow hot and cold, but what's the difference between the two?

Two main types of volcanoes exist in space. The first and most familiar is the type that spews out molten rocks, typically at high temperatures of at least 700 degrees Celsius (1,292 degrees Fahrenheit). These exist on terrestrial planets and moons that are composed primarily of metals or silicate rocks – in our Solar System they tend to be closest to the Sun. When they erupt, magma leaves the volcano and reaches the surface; it then becomes known as lava. The volcanoes on Io, Venus and Mars – both active and extinct – are of this type. Our Moon has also had such volcanism. "Recently, volcanism that was around 100 million years old was discovered on the Moon," says Khan, pointing to NASA's Lunar Reconnaissance Orbiter, which showed the Moon's volcanic activity gradually slowed over time.

The second type of volcano is very different. Cryovolcanoes, which are colloquially known as ice volcanoes, still have a heated interior, but they spew water mixed with ammonia or methane rather than molten rock. Cryovolcanoes exist on icy moons such as Enceladus and Titan, which circle Saturn. "The water that comes up from the liquid ocean beneath the icy crust of these moons behaves very similarly to lava," says Lopes. "It's defined as volcanism because it's a process of bringing material to the surface."



1 Tidal heating

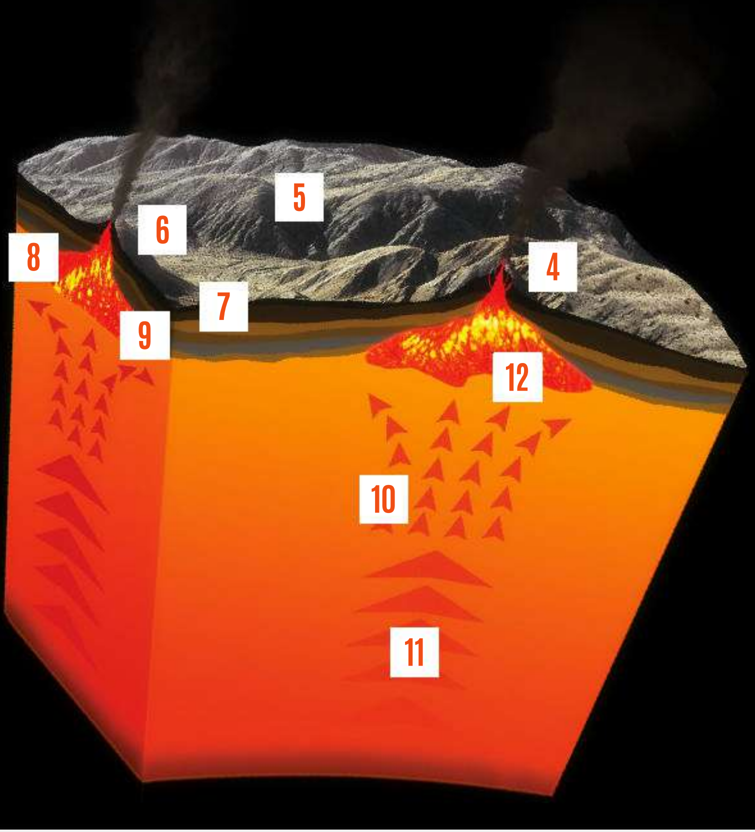
When there is tidal friction, the interior of the moon starts to become very hot.

2 Melting ice

It heats a pressurised H_2O pocket that melts ices. Because the heat has to somehow escape, it begins to push upwards to the body's surface.

3 Eruption

When it breaks through, it sends a water vapour plume and ice particles into the air. The friction heats nitrogen, which builds pressure and erupts.



4 Main vent

A composite volcano's magma escapes through a large main vent at the top.

5 Shield volcano

Wider than composites, they have gentle, sloping sides; lava is able to flow out easily.

6 Multiple eruptions

Layers of hardened lava build up. A conical appearance appears as a result.

7 The crust

Magma breaks through the crust on its route up to the surface.

8 Secondary vents

The magma seeks other outlets and can also escape through secondary vents.

9 Shield magma

The magma chamber of a shield volcano is spread over a wider subsurface area.

10 Lava channels

Venus has lava channels. Its longest is 6,800 kilometres (4,200 miles) long.

11 Rising magma

As magma rises, pressure builds. The buildup is more intense under a composite volcano.

12 Chamber

Beneath the surface is molten liquid rock, pooled in what is called a magma chamber.

© NASA

SCALING SPACE PEAKS

How does Mount Everest compare with some of the highest peaks in the Solar System?

1 Mount Everest

Location: Earth
Height: 8.8 kilometres (5.5 miles)
👣 40 days

2 Maat Mons

Location: Venus
Height: 4.9 kilometres (3.0 miles)
👣 20 days

3 Mons Rümker

Location: Moon
Height: 1.1 kilometres (0.7 miles)
👣 1 day

4 Ascraeus Mons

Location: Mars
Height: 15 kilometres (9.3 miles)
👣 85 days

5 Olympus Mons

Location: Mars
Height: 26 kilometres (13.6 miles)
👣 120 days

6 Arsia Mons

Location: Mars
Height: 11.7 kilometres (7.3 miles)
👣 58 days

7 Pavonis Mons

Location: Mars
Height: 8.7 kilometres (5.4 miles)
👣 43 days

8 Elysium Mons

Location: Mars
Height: 12.6 kilometres (7.8 miles)
👣 64 days

9 Boösaule Montes

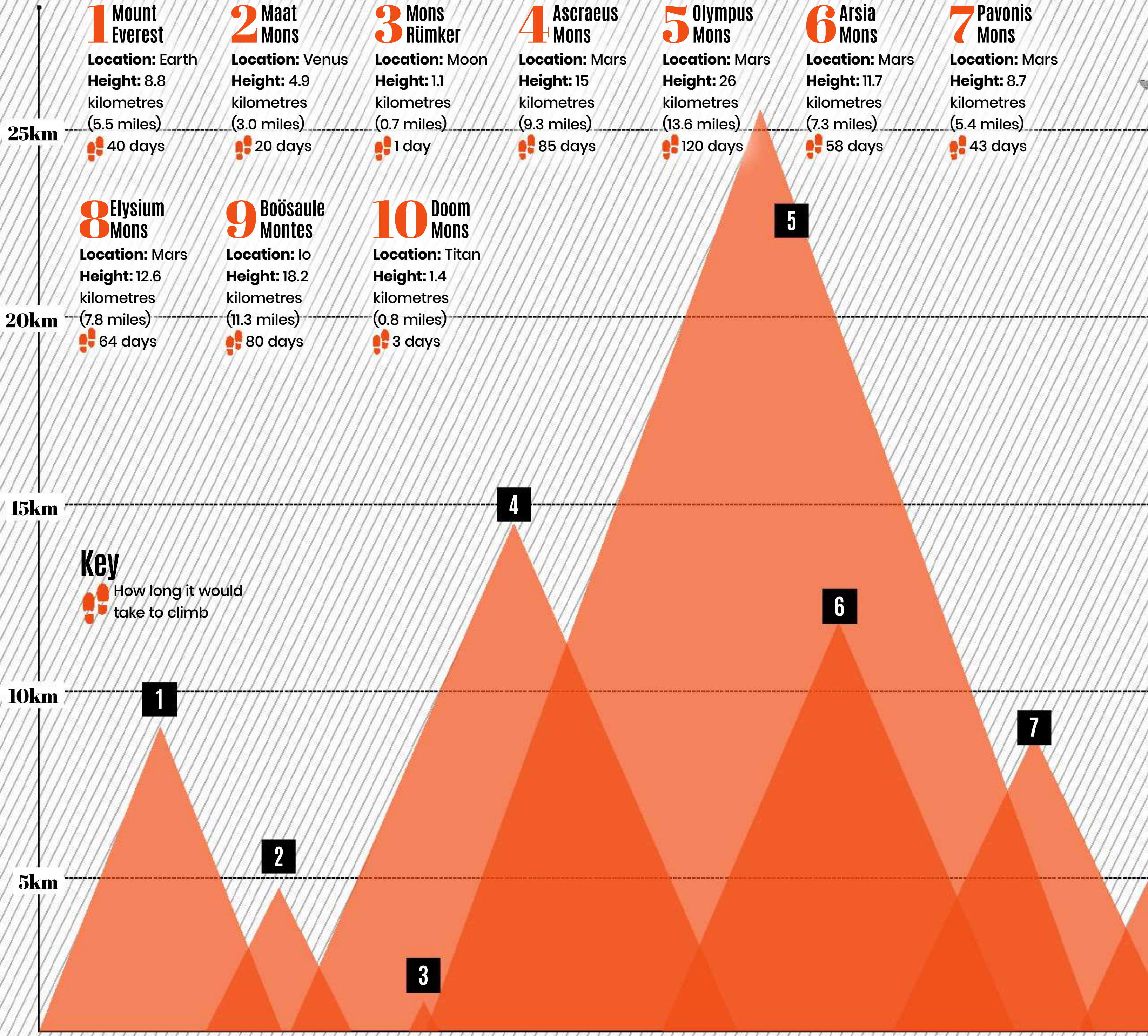
Location: Io
Height: 18.2 kilometres (11.3 miles)
👣 80 days

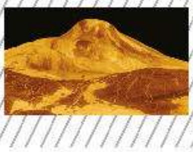
10 Doom Mons

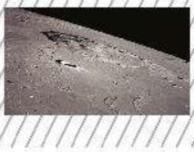
Location: Titan
Height: 1.4 kilometres (0.8 miles)
👣 3 days

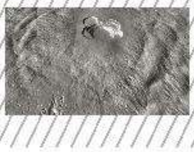
Key

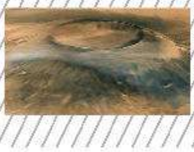
👣 How long it would take to climb



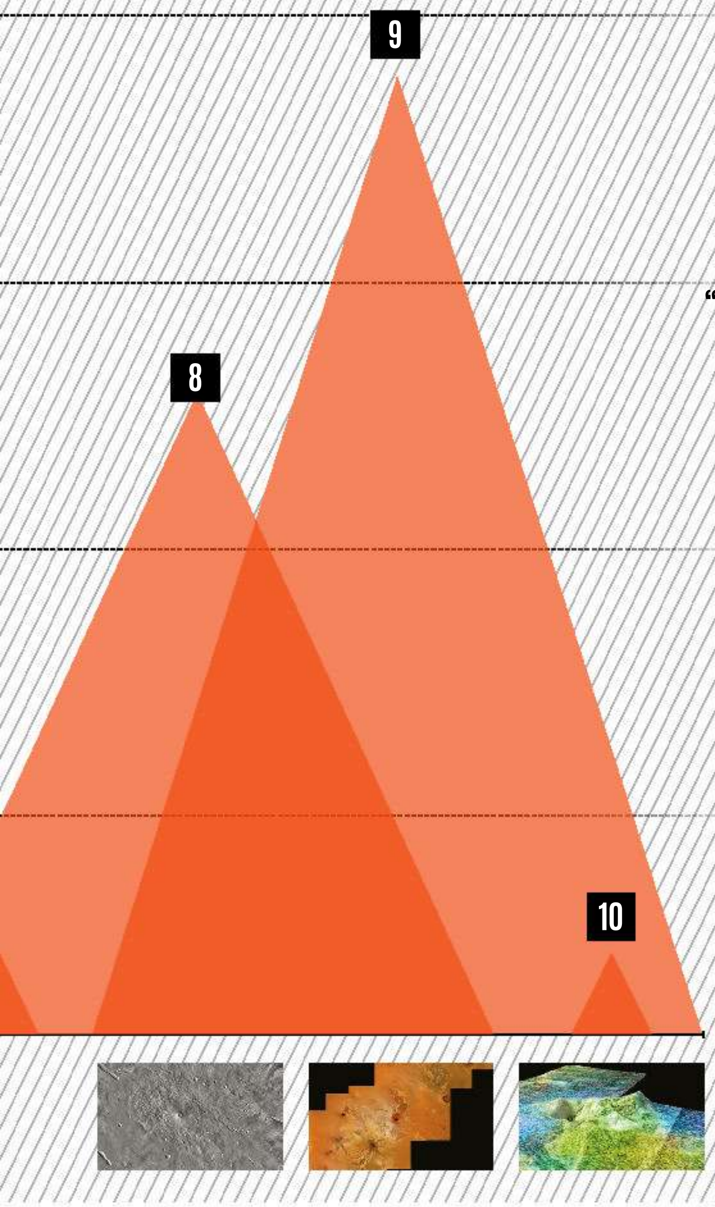








Ⓐ Dwarf planet Ceres has been found to have active cryovolcanism



Interestingly, there are differences in the ways similar types of volcanoes behave according to where they are. On Earth there is a relatively thin crust that's divided into several plates gliding over the mantle. This is referred to as plate tectonics. The crusts slowly move, crash and slide into each other, propelled by the incredible heat simmering below them. When one plate is forced below another in a process called subduction, the magmas that come out in those places tend to be more viscous, forming explosive cone-shaped volcanoes. When they pull apart, more fluid basaltic lava comes out, creating shield volcanoes that erupt effusively, rather than violently. Plate tectonics are an alien concept on Io, where volcanic activity originates from the tidal forces associated with its planetary host, Jupiter. Io was not expected to have volcanoes since it is a small body and should have cooled a long time ago, like Earth's Moon. But as it rotates around Jupiter it is effectively squeezed as it gets closer to the planet in its orbit then moves away. Its surface is constantly being bent and flexed, creating the necessary heat for volcanism. It's like taking a ball of wax and massaging it, making it hotter and hotter inside.

"It's unusual because Io is around the size of Earth's Moon and it should have lost a lot of its primordial heat, just like the Moon has. It should have cooled down," says Dr Lopes. "But Io is in a peculiar orbit and it has the gravitational pull of Jupiter. At the same time, the other satellites further away from Io are also experiencing this pull. The constant tug-of-war causes friction, creating heat and ensuring the interior of Io remains very molten. That is what drives volcanism."

> **"We want to know what is creating these lava lakes and how the eruption mechanisms work"**
>
> **Rosaly Lopes**

As volcanoes erupt on Io, it affects the entire Jovian system. The plumes, says Dr Michael Khan, who works in the mission analysis office of the European Space Operations Centre at the European Space Agency (ESA), produce a ring of charged material around Jupiter and "create a very nasty environment" as around 2 trillion watts of power is generated. "All of the stuff gets electrically charged. If you want to fly a spacecraft there, it gets hit by the charged particles and all of the electronics fry. It's not a nice thing to happen."

But the differences between volcanoes on different planets go beyond the causes of activity. Even patterns of eruption can be dissimilar, as is the case on Venus. "Venus can go hundreds of millions of years with no activity," says Khan. "Then everything goes off at once and the surface is completely remodelled." Volcanoes cover around 90 per cent of Venus and its surface has been transformed by volcanic eruptions. According to Lopes, who documented planets in her book *Alien Volcanoes*, the Magellan spacecraft found Venus' volcanism to be young in geological terms. "There are about 1,000 volcanoes, but I haven't counted them," she jokes. "The surface is really volcanic, but we don't know that much about it because it's a very challenging environment. The same is true of Io, as the environment is very radiation intensive."

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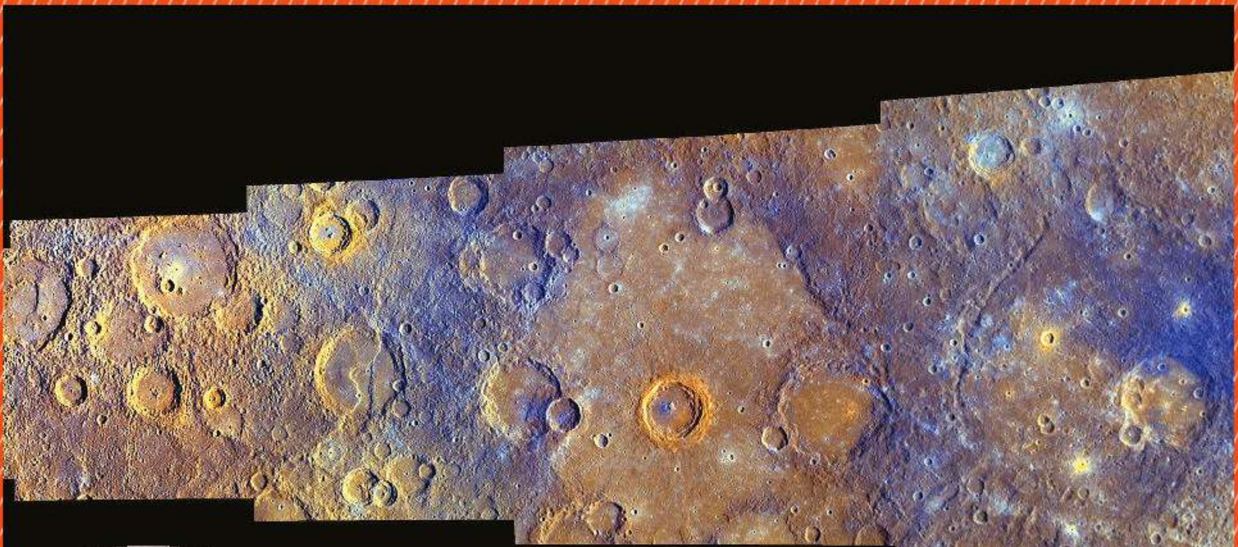
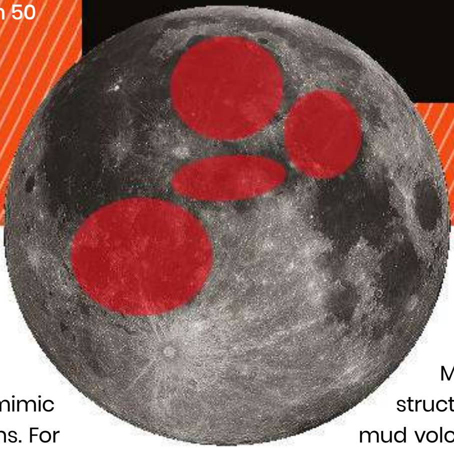


The robotic space probe MESSENGER spent four years orbiting Mercury, uncovering the planet's volcanic past. Hills, vents and long channels have been photographed. One of the volcanoes was thought to have erupted for a billion years



Most of the Moon is covered with hardened lava, made up of old basaltic flows. Some volcanic features may be less than 50 million years old

Planetary volcanism can mimic that of the moons. For instance, Mars has dozens of volcanoes that are large and dominant, and this is believed to be due to lower surface gravity. A thicker crust and higher eruption rates allow lava to pile on top of lava, creating extra height and bulk. Olympus Mons is 25,000 metres (82,021 feet) high; not only is it three times as high as Mount Everest, but its footprint would also cover the entirety of Germany. If it existed on Earth at that size and weight, it would break through the crust and go right to the mantle. Mars also has limited plate movement, meaning the lava buildup only has certain areas in which it can break through. The surface of Mars is effectively two large tectonic plates that have been rubbing against each other.

“Volcanoes are so different,” says Lopes. “While we have instrumentation that can give us geophysical measurements and an idea of what's underneath a volcano, there's a lot that we surprisingly don't know. There may be peculiar conditions that will make volcanoes erupt in a certain way. You only have to look at Mount Saint Helens in Washington, which erupted in 1980. Scientists were expecting the blast to go up, but it went sideways. A lot of people weren't evacuated because the scientists weren't modelling for it to go this way.”

Mars may also have geological structures that are referred to as mud volcanoes. They are similar to the geysers in Iceland, spewing dirt from beneath the ground. A region called Acidalia Planitia in the northern plains of Mars appears to have a fair few of these, and they are also found on Earth – there is a large concentration in Azerbaijan and the adjacent Caspian Sea. “It may explain the plumes of methane in the atmosphere of Mars,” says Khan, who notes that the drastic differences and completely unpredictable natures of many volcanoes make for some very intriguing observations. “It tells us how differently planets can evolve even though they were created at the same time and relatively close to each other,” he says. “If you look at the exoplanets around other millions and billions of stars, how this enormous variety of different geologies can exist is a lesson that the Solar System is teaching us. It also shows that the conditions for life may exist in situations where you wouldn't think it is possible.”

By way of explanation he points to Europa, another of Jupiter's geologically active moons. Like Io, it has been deformed by tides as it orbits the giant planet, releasing heat through rock-and-ice friction. Hubble revealed the icy moon spouting water in 2013, showing that the hypothesis of an underground ocean was probably correct. “Volcanic vents locally heat up the water, and eruptions happen,” explains Khan. “Volcanism could be an enabler for life on Europa because it has warmth, nutritious minerals and water, which are the basic ingredients.”

But just as some astronomers are looking for signs of life, others are keen to discover volcanic activity on other bodies. “It's why it's important to spread your studies to other planets,” says Lopes. “You never know what you may learn. Before we started studying Io, people wouldn't have imagined a moon that size could have active volcanism, but it does. There are certainly things we want to know about volcanism on Io, the big mystery being the composition of the lava. Studying this would help us understand lava from the early Earth.” Better equipment is helping enormously. “There have been a lot of advances in telescope instrumentation and techniques,” says Lopes. “We are getting to the point where we may have smaller and cheaper telescopes that can observe these volcanic bodies very frequently.”

David Crookes

Science and technology journalist

David has been reporting on space, science and technology for many years, has contributed to many books and is a producer for BBC Radio 5 Live.

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SCAN ME

FOCUS ON

THE 'BOUNCING' UNIVERSE THEORY STILL CAN'T EXPLAIN WHAT CAME FIRST

Research shows that a new model of a cosmos with endless periods of expansion and collapse still needs a beginning

Reported by Robert Lea

New research highlights a troubling problem with concepts of a cyclical universe that experiences infinitely alternating periods of rapid expansion and contraction. These bouncing universe models suggest the cosmos has no beginning, eliminating the need for a singularity prior to the initial period of rapid inflation needed by 'beginning of time' models.

University at Buffalo researchers say a newly suggested bouncing universe recipe that attempts to deal with the problem of entropy – the measure of unusable energy in the universe, which can only increase – suffers from a problem that has plagued previous models of endless inflation and contraction – it still needs a beginning. "People proposed bouncing universes to make the universe infinite into the past, but what we show is that one of the newest types of these models doesn't work," University at Buffalo (UB) physicist Will Kinney said. "In this new type of model, which addresses problems with entropy, even if the universe has cycles it still has to have a beginning." This means proponents of cyclical models of the universe may have to go back to the drawing board.

The leading theory of the universe's origins is so-called 'cosmic inflation.' This suggests that before time began all the energy in the cosmos was contained in a singularity – an infinite dimensionless point not described by the laws of physics. This ended with a period of rapid inflation that saw the universe expand and cool, thus allowing the formation of matter – first atoms of hydrogen, then heavier elements and eventually stars and galaxies.

The problem is, while this theory is very good at describing the universe as it ages from fractions of a second until the cosmic structure we see today, around 13.8 billion years later, it can't describe the conditions of the singularity that existed before this inflation began, or even what kick-started it.

This issue is eliminated by a bouncing universe because if periods of inflation and collapse are infinite then there was no beginning and thus no need to explain what preceded it. This would see the universe undergo similar inflation as suggested by the cosmic inflation model, but then 'springing back' on itself in a 'Big Crunch' of sorts. Each new inflation period would begin from the 'wreckage' of a previous period of expansion rather than a singularity. But Kinney thinks that bouncing universes come with their own unique problems.

"Unfortunately, it's been known for almost 100 years that these cyclic models don't work because disorder, or entropy, builds up in the universe over time, so each cycle is different from the last one. It's not truly cyclic," the researcher explained. "A recent cyclic model gets around this entropy buildup problem by proposing that the universe expands a whole bunch with each cycle, diluting the entropy."

Kinney said that this new bouncing universe model tries to stretch everything out to get rid of cosmic structures such as black holes, thus returning the universe to its original homogenous state before another bounce begins. "We showed that in solving the entropy problem you create a situation where the universe had to have a beginning. Our proof shows in general that

> "In this new type of model, which addresses problems with entropy, even if the universe has cycles it still has to have a beginning"
>
> **Will Kinney**

any cyclic model which removes entropy by expansion must have a beginning," he said, adding one bouncing universe may survive this assessment. "Our proof does not apply to a cyclic model proposed by Roger Penrose in which the universe expands infinitely in each cycle. We're working on that one."

Kinney's collaborator is University at Buffalo physics PhD student Nina Stein. She highlighted the problem the duo had with a bouncing universe: "The idea that there was a point in time before which there was nothing, no time, bothers us, and we want to know what there was before that – scientists included. But as far as we can tell, in models that address entropy there must have been a 'beginning.' There is a point for which there is no answer to the question what came before that?"

For now the mystery of what existed before the universe and time itself remains, and likely will be hotly debated by cosmologists for some time to come. "There are a lot of reasons to be curious about the early universe, but I think my favourite is the natural human tendency to want to know what came before," Stein said. "Across cultures and histories, humans have told stories about creation, about 'in the beginning'. We always want to know where we came from."

CLASSIC CYCLIC UNIVERSE

1 The Big Bang

Nearly 14 billion years ago our universe exploded into existence from an infinitely small, infinitely dense point called a singularity. This event is called the Big Bang.

2 The first galaxies

As the expansion continued, visible matter was drawn towards invisible dark matter to create the first structures in the universe.

3 Expansion isn't forever

The universe expands at an ever-slowing pace as the collective gravity of all its galaxies applies the brakes. It reaches a maximum size.

4 Gravity takes over

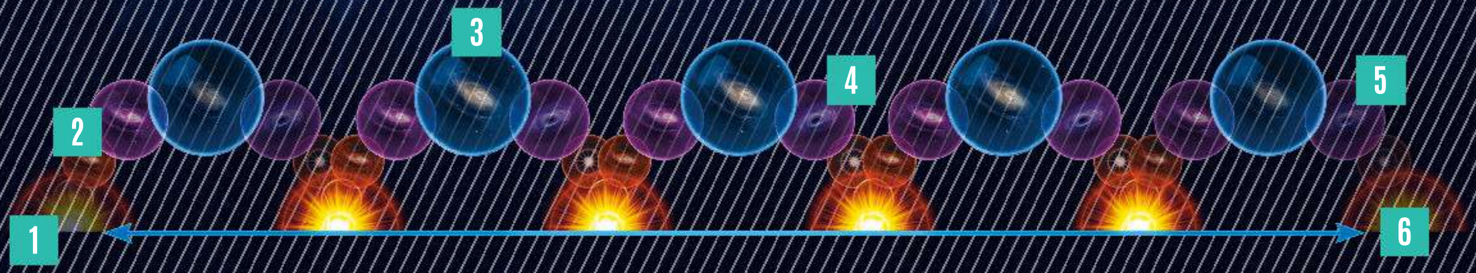
The universe starts to shrink as gravity draws the galaxies back together – a reversal of the period after the Big Bang.

5 Galaxy collisions and black holes

Galaxies begin to collide with each other and the universe gets smaller; black holes form as matter is crunched together.

6 The Big Crunch

Eventually everything is crushed down into a single singularity. This then explodes in another Big Bang to create a new universe.



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MYSTERIES OF THE UNIVERSE

WHY DO ASTRONAUTS EXPERIENCE MUSCLE LOSS?

Discover how sending worms into space is helping unlock ways for humans to spend longer beyond Earth

Reported by David Crookes

When astronauts are in space, their bodies are put under enormous pressure and strain. Aside from the mental stresses of spaceflight, astronauts are exposed to radiation and the effects of weightlessness, and loss of muscle is a major problem. Otherwise known as muscle atrophy, it affects the soft tissue in an astronaut's lower leg, hip, back and neck as well as in the quadriceps. These muscles usually work against the forces of gravity – hence why they're referred to as antigravity muscles – yet they're not needed to the same degree in a weightless environment, so they weaken and deteriorate.

A spaceflight lasting just 5 to 11 days will result in a muscle loss of 20 per cent, rising to 40 per cent after six months in space. It's why astronauts must engage in strength exercises for more than two hours each day and why they also effectively need to learn how to walk again once they're back on Earth. NASA's Scott Kelly, for example, spent 340 days on the International Space Station (ISS) in 2015 and 2016, and his legs appeared to be made of jelly following his return. Drew Feustel spent 197 days in space in 2018, and he posted a video on Twitter showing his unsteady steps as he struggled to walk forward.

But despite observations and documentation, scientists are still trying to determine the causes of these muscle changes during spaceflight. The aim is to figure out ways of preventing muscle loss, particularly if astronauts are going to be spending longer periods of time on the ISS in a microgravity environment or if they end up embarking on a lengthy planetary or lunar mission. How can this be done? It may surprise you to learn that researchers have turned to creatures that could make some of you squirm: tiny worms called *Caenorhabditis elegans*. These roundworms are just a millimetre in length, and they've been chosen because many of their genes have functional counterparts in humans. Study the worms and it's possible to get a clearer idea of what's happening in an astronaut's body.

"Worms and humans share roughly 40 per cent of genes," says Dr Nathaniel Szewczyk, emeritus professor of space biology at the University of Nottingham. "Both have muscles to enable them to move about. Both use insulin to maintain muscle and whole-body health. Both experience loss of muscle with age, inactivity and spaceflight. Both get muscle diseases such as Duchenne muscular dystrophy."

The worms are also small, quick to grow, cheap and easy to maintain and much is known about them because they are one of the simplest organisms. They were the first multicellular organism to have their genetic structure entirely mapped, with South African biologist Sydney Brenner establishing the roundworm as a model organism for the investigation of developmental biology. Of their 20,000 genes, ten per cent promote muscle function and as many as 60

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T. PEAKE
ПИК
esa
MOLECULAR MUSCLE EXPERIMENT 2
UK SPACE AGENCY

CAENORHABDITIS ELEGANS WORMS BY NUMBERS

20,500	Number of genes
1,000	Number of eggs produced daily
ONE	millimetre in length
14	Time taken, in hours, to hatch an egg
0	skeletal elements
302	neurons in their nervous system
THREE	Maximum life span in weeks
1,033	Maximum number of cells
TWO	sexes: male and hermaphrodite
1963	Year the worms were first studied

per cent of those have counterparts in the human body.

Szewczyk has been using these worms for his scientific experiment for years, studying muscle change and the effects on their bodies. He created a notable experiment in 2004 in which he and his team used the exact same worms to discover spaceflight had some potentially beneficial effects. In this study, involving scientists from France, the US, Canada and Japan, live worms were sent to the ISS across six occasions in total, culminating in a report in 2012 which suggested toxic proteins that normally accumulate within ageing muscle are suppressed during a flight into space. The research also found that genes which were expressed at lower levels during spaceflight would, when lowered within worms on Earth, actually help them live longer. "We identified seven genes which were down-regulated in space and whose inactivation extended life span under laboratory conditions," Szewczyk said at the time.

One of the early observations pointed to the genes being involved in how the worms sense the environment, signalling changes in metabolism in order to adapt. One identified gene encoded insulin, which is well known for controlling metabolism. In worms, flies and mice, insulin is also associated with the modulation of life span. Yet Szewczyk didn't stop there. In 2018 he was part of a team at both the University of Nottingham and the University of Exeter that wanted to go further and discover which molecules caused a loss of muscle. The experiment concentrated on observing muscular changes while the worms were in space. It also focused on the genes involved in insulin signalling and cell attachment. "Insulin and cell attachment signalling are two of the most consistently changed molecular pathways during spaceflight," says Dr Timothy Etheridge, one of the lead investigators.

WHAT CAN THE WORMS TELL US?

There are many benefits to be had by studying *Caenorhabditis elegans*

How ageing works

Since the worms only live between two and three weeks, scientists can easily study their entire life. They show visible signs of ageing, right down to the development of wrinkled skin, slower motility and reduced capacity for learning.

How muscle is lost

The worms are molecularly similar to humans and their muscles work in much the same way. By sending them to the ISS – and beyond – scientists can study changes to their bodies and identify which molecules are causing problems.

How to cure disease

Scientists studying the genetic and molecular mechanisms of the worms can learn more about various conditions and diseases, including cancer. The transparency of the worms allows researchers to see cell mutations.

This also involved sending thousands of tiny *Caenorhabditis elegans* worms into space, with the aim of studying them intensely. It became the first UK experiment to take place on the ISS and also looked to study the metabolic changes that see fluid redistributed from the legs to the head – an astronaut's total body water decreases by up to three per cent in just two days. The study's importance also grew as the appetite for low-Earth orbit missions became stronger.

"Since the advent of the ISS and the ability to more frequently study astronaut muscle, we now know that, like on Earth, a proper diet and proper amount of physical activity can successfully mitigate muscle loss," Szewczyk tells **All About Space**. "While this is great news, the exercise equipment used on the ISS is too large for current beyond low-Earth orbit missions, for example Artemis and Gateway. Similarly, providing a proper diet as we move beyond low-Earth orbit becomes a major operational challenge."

As you'd expect, preparations for the worm astronauts were stringent and well-considered. As well as placing the worms into a liquid bacterial feed, they were sealed inside a special gas-permeable plastic bag. They were then housed in a special incubator by an astronaut on board the ISS and allowed to reproduce in space. The idea was to wait for them to spend six-and-a-half days growing into adults, at which point they were frozen. After the worms were returned to Earth, the team – working under the banner of the Molecular Muscle Experiment – looked at the biological changes which had taken place. The scientists examined the changes to the worms' muscles as well as the worms' ability to use energy.

Things didn't always go quite as planned, however. Mouldy food found in the kit of another research team meant a SpaceX rocket carrying thousands of worms in 2018 had to be delayed by 24 hours. There was much frustration because the worms would only just be turning into adults at the time of the launch and there were fears the delay meant they'd be too old for research. Even so, the research team had backup colonies, and very little was left to chance.

There was a wider issue at stake here, too. Although the funding and support for the study was to primarily enable future

When astronauts such as Tim Peake land, they usually need to be carried to a medical facility because they can't initially walk well

Since bones and muscles don't have to support an astronaut's mass in space, atrophy soon sets in, which is why ongoing research is important

A transparent adult *Caenorhabditis elegans* worm

© NASA; Source: Wikipedia Commons © Kdradnam

HOW AN ASTRONAUT'S BODY SUFFERS IN SPACE

Being on the International Space Station certainly takes a toll on humans

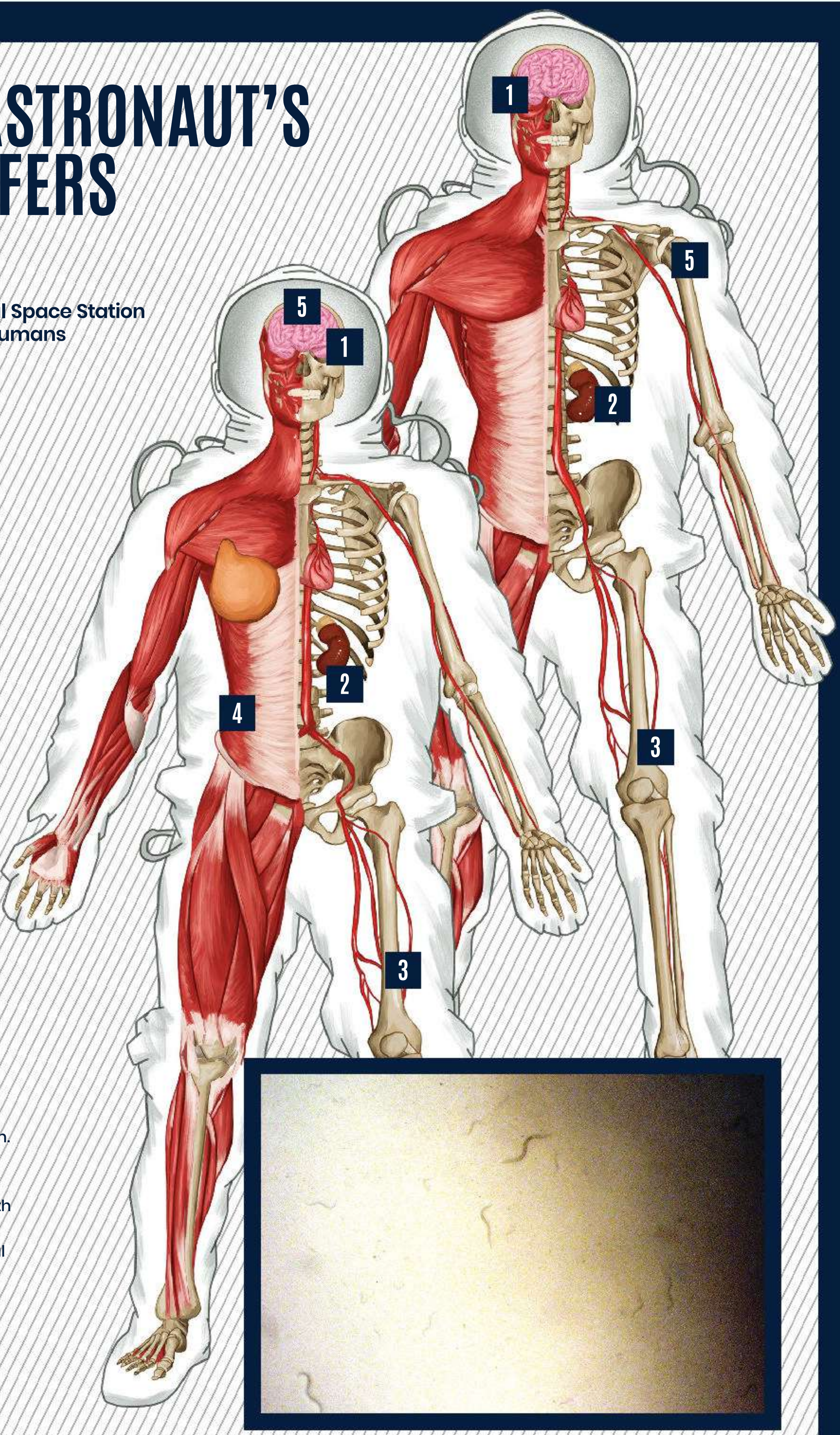
1 Visual impairment
Being in space can affect an astronaut's eyesight. It can cause swelling of the optic disc and cause the structure of the eye to change due to a shift in fluids towards the head. Men appear to be worse affected.

2 Kidney stones
Kidney stones are common among astronauts who have flown into space, and passing them out of the body is very painful. A loss of calcium in the blood or dehydration may be to blame.

3 Muscle and bone loss
There's a strong link between microgravity environments and a dramatic drop in muscle mass and bone density. Astronauts must exercise to counteract this.

4 Greater chance of cancer
Studies have shown that radiation exposure can lead to cancer, particularly among female astronauts. The permissible radiation exposure for women is lower than for men.

5 Feeling of isolation
Being so far away from Earth and only having a handful of people around has the potential to cause problems for mental health. A daily structure and thorough training is essential.



⬆ The Kubik incubator contains the experiment canisters

➡ An astronaut completing a Molecular Muscle Experiment on the ISS

↙ *Caenorhabditis elegans* worms as seen under a microscope in 2003

space exploration, understanding the causes of muscle problems allows therapies to be developed to tackle them. This also potentially benefits people who don't intend to ever leave planet Earth by shedding fresh light on human muscular conditions. It could lead to better treatment for muscular dystrophies.

So what came of the 2018 roundworm study? In November 2020, the University of Exeter revealed the results of genetic analyses on the worms that had been returned from the ISS. They found there had been subtle changes in about 1,000 genes caused by hypergravity, experienced during takeoff, and microgravity. The way in which the worms' bodies worked had appeared to destabilise.

Working with the NASA GeneLab, it was discovered that the worms' nervous system cells, or neurons, were particularly impacted. These cells transmit data between parts of the brain and nervous system and also send information to the muscles and gland cells. Cellular metabolism was noted to be affected by gravitational changes too. "We looked at levels of every gene in the worms' genome and identified a clear pattern of genetic change," says Etheridge. "These changes might help explain why the body reacts badly to spaceflight. It also gives us some therapy targets in terms of reducing these health effects, which are currently a major barrier to deep-space exploration."

To build upon the findings, scientists at the University of Exeter and the University of Nottingham created a second study, Molecular Muscle Experiment 2. "In this particular experiment we were specifically testing drugs that improve worm – and in some cases human – muscle health on Earth for their ability to do the same in space," Szewczyk says. To this end, more roundworms were launched into space in 2021, following much the same procedure as before. Once again using hardware designed by Kayser Space, which is based in Oxford, the study entailed storing the worms at ten degrees Celsius (50 degrees Fahrenheit) during the set up and journey to the ISS.

Once on board, the experimental containers were placed into a small Kubik incubator within the European Space Agency's Columbus ISS module. They were stored at 20 degrees Celsius (68 degrees Fahrenheit) for five to six days before being frozen and eventually returning. By having a control group as well as a batch of worms grown in the exact same conditions on Earth, it allowed for a clear comparison between Earth gravity and microgravity.

> **"Proper diet and proper amount of physical activity can successfully mitigate muscle loss"**
> **Nathaniel Szewczyk**

As well as looking to discover the precise molecules which affect muscle and metabolism, the team tested therapies that could prevent muscle loss in zero gravity. "So far we are still waiting to process the UK flight samples; they only just arrived at Exeter in August this year," Szewczyk says. "Samples from our international collaborators have revealed that dopamine signalling is altered in flight, however, and that maintenance of neurons is altered in flight. We have also shown that one of the drugs we are testing in flight improves health in worms with Duchenne muscular dystrophy on Earth."

The hope is that it will pave the way for future long-term missions to the Moon and Mars, helping astronauts to retain as much muscle mass as possible while also being able to slip more quickly into terrestrial life upon their return to Earth. "We have also been working on a payload called Deep Space Petri Pod that would enable studying worms on other celestial bodies – we have baselined a Mars mission – and we are currently examining cubesat mission options and applying to NASA for a slot on Artemis II," Szewczyk says.

With about 70,000 worms sent last year, there's certainly scope for amassing copious amounts of data. "Since worms are so small, we can use hundreds or thousands to improve the replicability of results, thus making work trials a bit more like large clinical trials than studies of individuals," Szewczyk says. "Additionally, because they are so small we can fly numerous experiments and interventions. For example, Molecular Muscle Experiment 2 had 24 different individual investigations, each on thousands of worms and each repeated in three sets of worms."

But keeping astronauts strong is important, and the research certainly has the backing of those fortunate enough to venture to the ISS. "This experiment will give us new information on the molecules that cause muscle decline in space and whether targeting these with novel drugs and interventions can help," says Etheridge. "This information can then build the foundations for safely sending humans on long-term missions into deep space."

David Crookes
Science and technology journalist
David has been reporting on space, science and technology for many years, has contributed to many books and is a producer for BBC Radio 5 Live.

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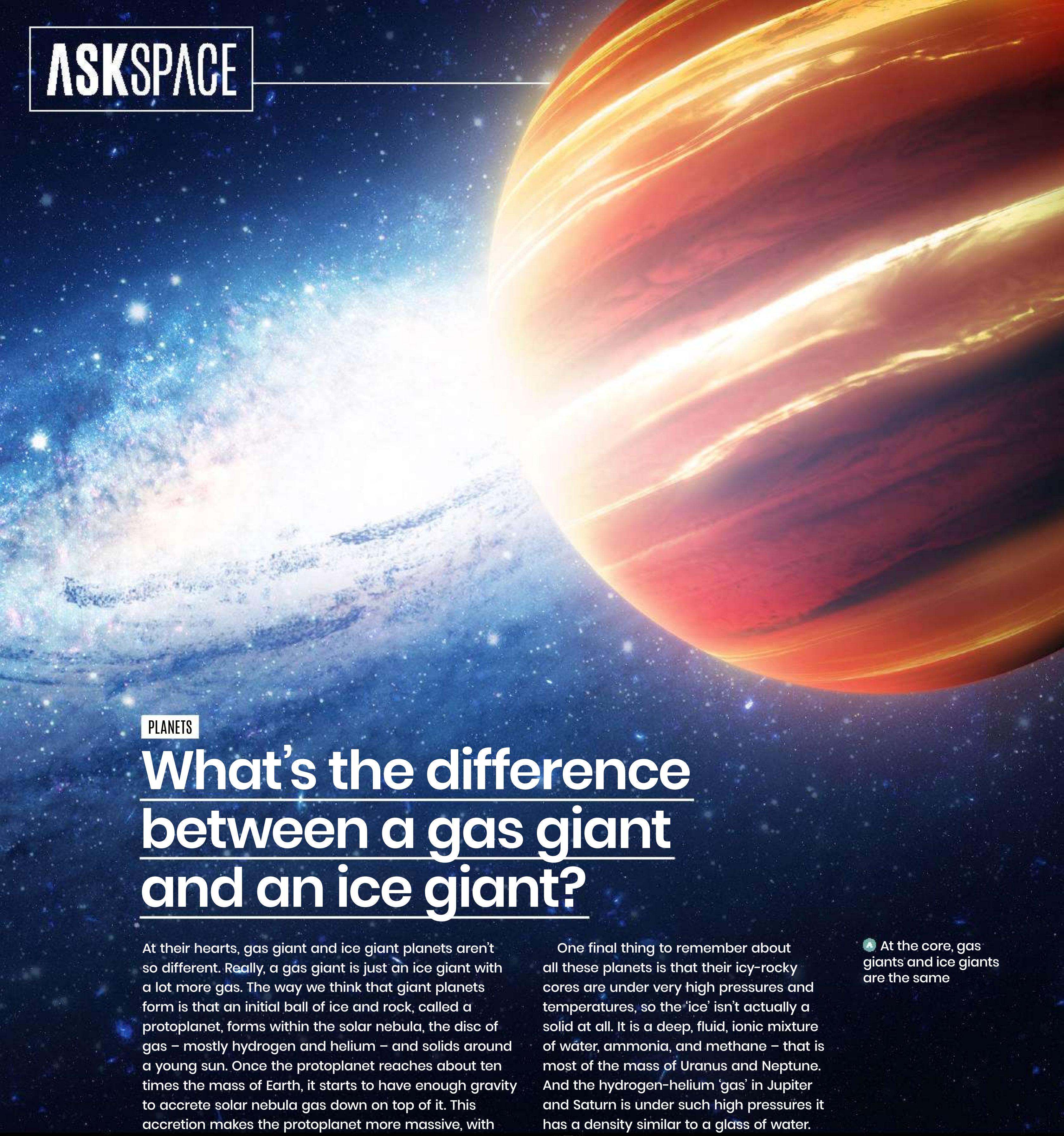


A At the core, gas giants and ice giants are the same

PLANETS

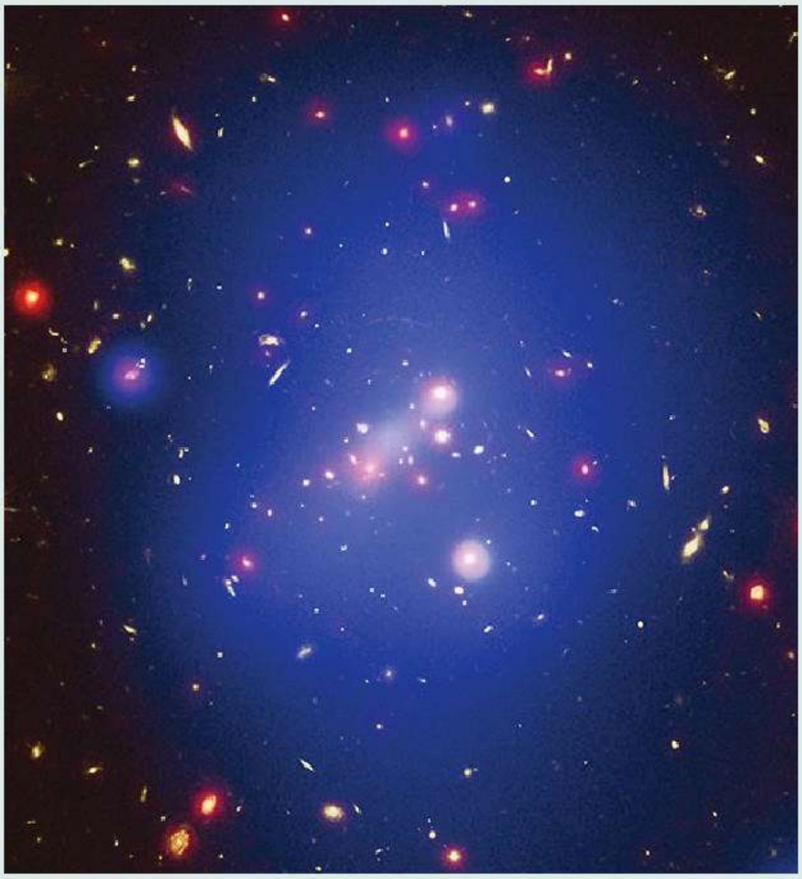
What's the difference between a gas giant and an ice giant?

At their hearts, gas giant and ice giant planets aren't so different. Really, a gas giant is just an ice giant with a lot more gas. The way we think that giant planets form is that an initial ball of ice and rock, called a protoplanet, forms within the solar nebula, the disc of gas – mostly hydrogen and helium – and solids around a young sun. Once the protoplanet reaches about ten times the mass of Earth, it starts to have enough gravity to accrete solar nebula gas down on top of it. This accretion makes the protoplanet more massive, with an even better ability to grab even more gas. This gas accretion process can almost reach a runaway, with more and more gas piling on top.

The initial protoplanet is therefore the 'seed' for planetary formation, and that part becomes the planet's core. Uranus and Neptune, our ice giants, only accreted a few Earth masses of gas, while Saturn accreted several dozens of Earth masses and Jupiter about 300.

One final thing to remember about all these planets is that their icy-rocky cores are under very high pressures and temperatures, so the 'ice' isn't actually a solid at all. It is a deep, fluid, ionic mixture of water, ammonia, and methane – that is most of the mass of Uranus and Neptune. And the hydrogen-helium 'gas' in Jupiter and Saturn is under such high pressures it has a density similar to a glass of water.

Jonathan Fortney, professor at the University of California, Santa Cruz



About 26.8 per cent of the universe is dark matter

ASTROPHYSICS

How hot is dark matter?

Competing theories suggest that dark matter may be cold, warm or hot. The temperature refers to particles' speed. Cold dark matter particles sit still, like water molecules frozen in ice; hot dark matter particles zip about like molecules in steam, spreading into their surroundings. The speed of dark matter particles mattered when they emerged from the Big Bang. Set loose in computer simulations, cold dark matter particles don't move. Gravity pulls them together, creating lumps in the primordial soup. Hot dark matter particles whiz around near the speed of light, stirring it up. Fortunately for us, most real dark matter was tepid. It created lumps that eventually grew into habitable galaxies like the Milky Way. Confusingly, the theories' names have nothing to do with the present speed of dark matter particles. Our universe expanded so rapidly that the initial motion of any dark matter particles became irrelevant. Then particles fell into galaxies, picking up speed. Dark matter particles in the Milky Way now move 20 kilometres (12.4 miles) every second. That's twice as fast as hydrogen on the surface of the Sun.

Richard Massey, Royal Society research fellow at the Institute for Computational Cosmology at Durham University

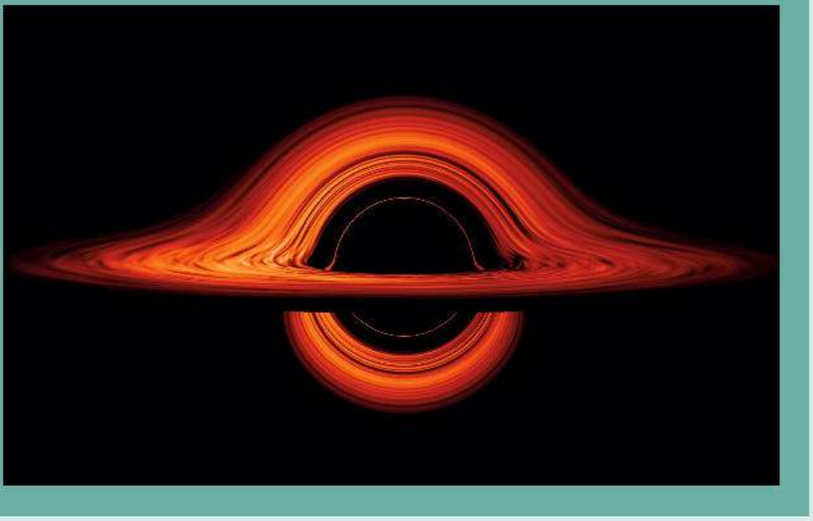
ASTROPHYSICS

What is a photon sphere?

A hundred years ago, Albert Einstein truly became a household name when his theory of relativity was first tested and confirmed by experiments. Einstein predicted that light passing by a massive object should get deflected by gravity, and that this effect could even be detected by measuring the apparent location of stars near the Sun during a solar eclipse. For the Sun, this deflection is less than a thousandth of a degree. For a black hole, with its much stronger gravitational field, the light ray can get bent by 360 degrees or more.

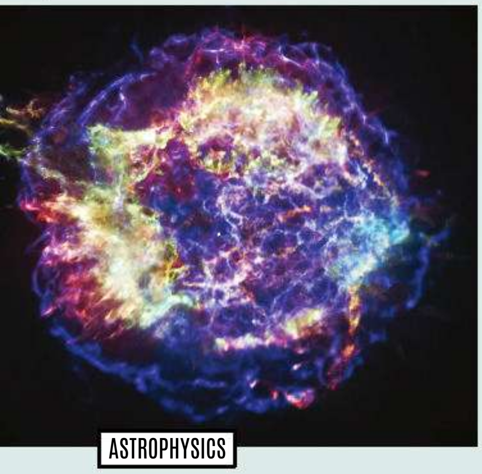
Imagine shining a laser pointer at a black hole. If you point it right at the black hole, the light will get swallowed by the horizon. If you point it to the side, it will get deflected by the black hole's gravity, but still reach the other side. But as you point the laser closer and closer to the black hole's edge, there's a point where the light just barely doesn't get captured, but also doesn't escape. Instead it just orbits around and around in a perfect circle. This is what we call the 'photon sphere' of a black hole. For non-spinning black holes, the photon sphere radius is 50 per cent bigger than the horizon radius, but for rapidly rotating black holes, the photon sphere snuggles right up against the horizon, allowing light to orbit many times without falling in and without falling out.

Dr Jeremy Schnittman, research astrophysicist at NASA's Goddard Space Flight Center, Maryland



A black hole's gravity alters light coming towards it

© NASA; Tobias Roetsch



ASTROPHYSICS

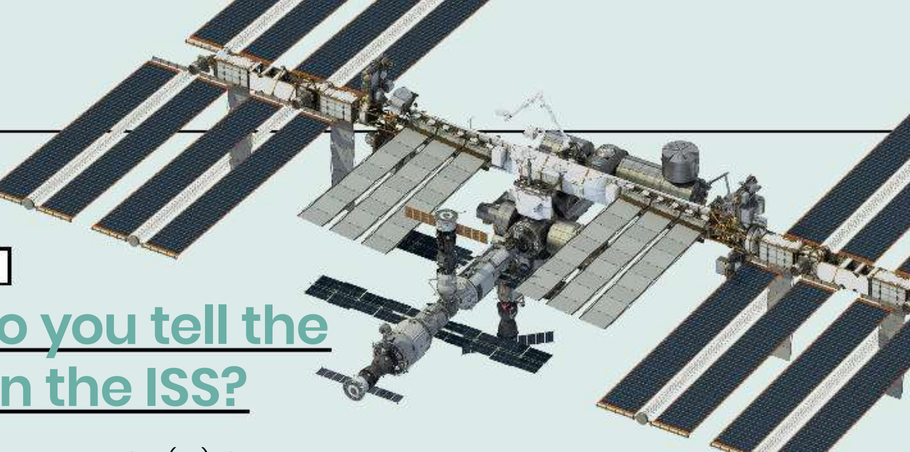
Could you ride a supernova wave?

Supernovae are the explosions of stars. Only certain types of stars explode – not to worry, our Sun isn't one of them – and when they do they shine as bright as 100 billion Suns and throw out material at thousands of kilometres per second. That would be quite the surf to ride!

For most supernovae – those which are the explosions of massive stars – the material that is flying out is made up of the elements that the star produced during its life: helium, calcium, oxygen, carbon and so on up to iron. Even heavier elements are made in the explosion itself. Such supernovae are the only places we know of in the universe where these elements are created and released into space. This means that every calcium atom in our bones, every oxygen atom we breathe, every iron atom in our blood, all were part of a supernova, sometime, somewhere, and made their way to our bodies through the material that gathered to make the Sun, Earth and eventually us. In that sense we are all made of particles that rode a supernova wave at some point in their past.

Dr Iair Arcavi, observational astronomer and assistant professor at Tel Aviv University

© NASA; Getty; Adrian Mann;



SPACE EXPLORATION

How do you tell the time on the ISS?

The International Space Station (ISS) flies around Earth at 28,160 kilometres (17,500 miles) per hour, completing each orbit in 90 minutes, which means the crew see 16 stunningly beautiful sunrises and sunsets every 24 hours. This means that the crew can't use the passing of the Sun to help mark out days, and instead had to pick a time zone. It's the same time on the ISS as it is in Iceland and Ghana. That's because the space agencies around the world that built the station decided that it should use Coordinated Universal Time, or UTC.

This is a convenient compromise between the times in Houston and Moscow, the two cities where the two main control centres for the ISS are located, and means that the flight controllers in each country have their days overlapping with half of the crew's day. Once a new crew arrives at the station, they can simply set their wristwatches to the new time zone, just like you might when travelling, and then settle into their new home up in the sky.

Libby Jackson, human exploration program manager at the UK Space Agency

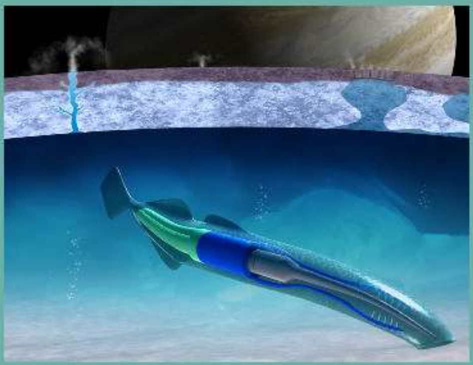
The ISS experiences many sunrises and sunsets as it orbits Earth

Astronomers have observed evidence for favourable conditions under the icy crust of Europa

SOLAR SYSTEM

What evidence have we found that there could be life on Europa?

Jupiter's moon Europa is believed to have a global ocean about 20 kilometres (12 miles) beneath its icy surface. On Earth, essentially everywhere there is liquid water, there is life. Europa's ocean could be Earth-like in its temperature and salinity. The second ingredient for life is the chemical elements from which organic molecules are built: carbon, hydrogen, nitrogen, oxygen, phosphorous and sulphur. Europa probably formed with these, gaining more as comets and asteroids impacted the moon. The third ingredient is energy to power life. On Earth, most energy for metabolism comes from sunlight, which drives photosynthesis. Other Earth microorganisms are powered by chemical energy, where molecules chemically react to form new molecules while storing energy. We need to better understand whether Europa's ocean can support life powered by chemosynthesis.



Dr Robert Pappalardo, project scientist on NASA's Europa Clipper mission

Galactic mergers can give rise to new galaxies

GALAXIES

Can galaxies die?

It very much depends on how you define a galaxy being alive. A common definition is that a galaxy is alive if it's forming new stars, and by that definition, galaxies can – and often do – die. Any galaxy we see that is very red in colour has mostly stopped forming stars – the blue stars that formed with the red ones die off the quickest, leaving the red ones behind.

There are many reasons a galaxy might stop forming stars. Maybe it's out of the gas needed to form new stars. Maybe the gas is there, but simply too hot to be able to cool and collapse down into a star. The end result is the same in both cases: no new stars. On the other hand, you could choose a more lenient definition – if it exists, it's alive. To die would thus be to have the galaxy disappear entirely. The closest we get is if the galaxy were to merge with another galaxy. It would then build a new galaxy with its companion, marking the end of its previous existence. Though it hasn't disappeared, it's had all of its pieces folded, like clay, into a new form.

> "Any galaxy that is very red in colour has mostly stopped forming stars"

Dr Jillian M. Scudder, department of physics and astronomy, Oberlin College and Conservatory

WHAT'S IN THE SKY?

What to look out for during this observing period

In this issue...

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80 **Planetarium** Where you can find the planets this month and the phases of the Moon

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85 **Naked eye and binocular targets** On crisp autumn nights find galaxies, beautiful star clusters and a demonic star

86 **Deep sky challenge** Among the richest for deep-sky observers, September brings star clusters, nebulae and galaxies galore

88 **The Northern Hemisphere** The longer nights are upon us, so enjoy both Solar System and deep-sky objects

90 **Your astrophotos** The best of our readers' astrophotography images

92 **Review** We put the Celestron PowerSeeker 127EQ to the test

96 **In the shops** Our pick of the best gifts and accessories for astronomy and space fans

11 SEPTEMBER

Conjunction between the Moon and Jupiter in Pisces

11 SEPTEMBER

The Moon and Jupiter make a close approach, within 1°36' of each other in Pisces

14 SEPTEMBER

The Moon passes in front of Uranus, visible from Asia, Africa and Europe

14 SEPTEMBER

The Moon and Uranus pass within 44.1 arcminutes' of each other in Aries

16 SEPTEMBER

Neptune reaches opposition, glowing at magnitude +7.8 in Aquarius

17 SEPTEMBER

The Moon and Mars make a close approach, within 3°32' of each other in Taurus

17 SEPTEMBER

Conjunction between the Moon and Mars in Taurus

Red-light friendly

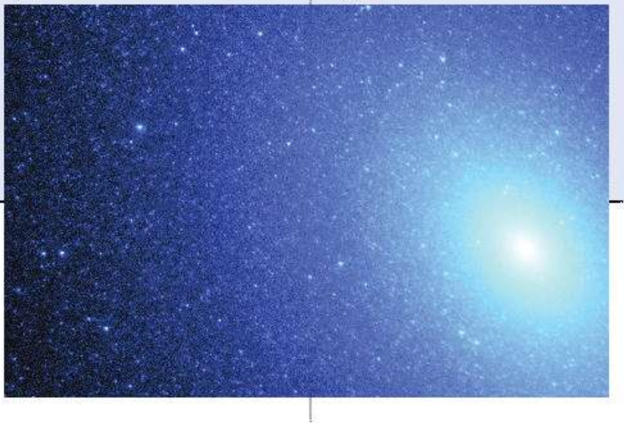
In order to preserve your night vision, you should read our observing guide under red light

23 SEPTEMBER

September equinox

26 SEPTEMBER

Jupiter reaches opposition, glowing at magnitude -2.9 in Pisces



1 OCTOBER

Galaxy Messier 110 is well placed for observation in Andromeda

2 OCTOBER

Galaxy Messier 32 is well placed for observation in Andromeda

5 OCTOBER

Conjunction between the Moon and Saturn in Capricornus

Naked eye

TAKE CARE!
Naked eye warning

Binoculars

Small telescope

Medium telescope

Large telescope

Solar eclipse

Solstice

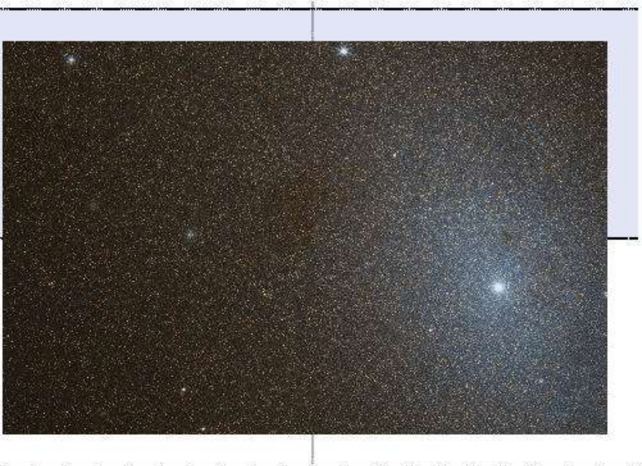
2 OCTOBER

The Andromeda Galaxy (Messier 31) is well placed for observation in Andromeda

> "The Moon passes in front of Uranus, visible from Asia, Africa and Europe"

5 OCTOBER

The Moon and Saturn make a close approach, within 3°51' of each other in Capricornus



6 OCTOBER

The October Camelopardalid meteor shower reaches its peak

Jargon buster

Conjunction

An alignment of objects at the same celestial longitude. The conjunction of the Moon and the planets is determined with reference to the Sun. A planet is in conjunction with the Sun when it and Earth are aligned on opposite sides of the Sun.

Declination (Dec)

How high an object will rise in the sky. Like Earth's latitude, Dec measures north and south in degrees, arcminutes and arcseconds. There are 60 arcseconds in an arcminute and 60 arcminutes in a degree.

Opposition

When a celestial body is in line with Earth and the Sun. During opposition, an object is visible for the whole night, rising at sunset and setting at sunrise. At this point in its orbit, the celestial object is closest to Earth, making it appear bigger and brighter.

Right Ascension (RA)

RA is to the sky what longitude is to Earth, corresponding to east and west. It's measured in hours, minutes and seconds, as since Earth rotates on its axis, we see different parts of the sky throughout the night.

Magnitude

An object's magnitude tells you how bright it appears from Earth, represented on a numbered scale. The lower the number, the brighter the object. A magnitude of -1.0 is brighter than +2.0.

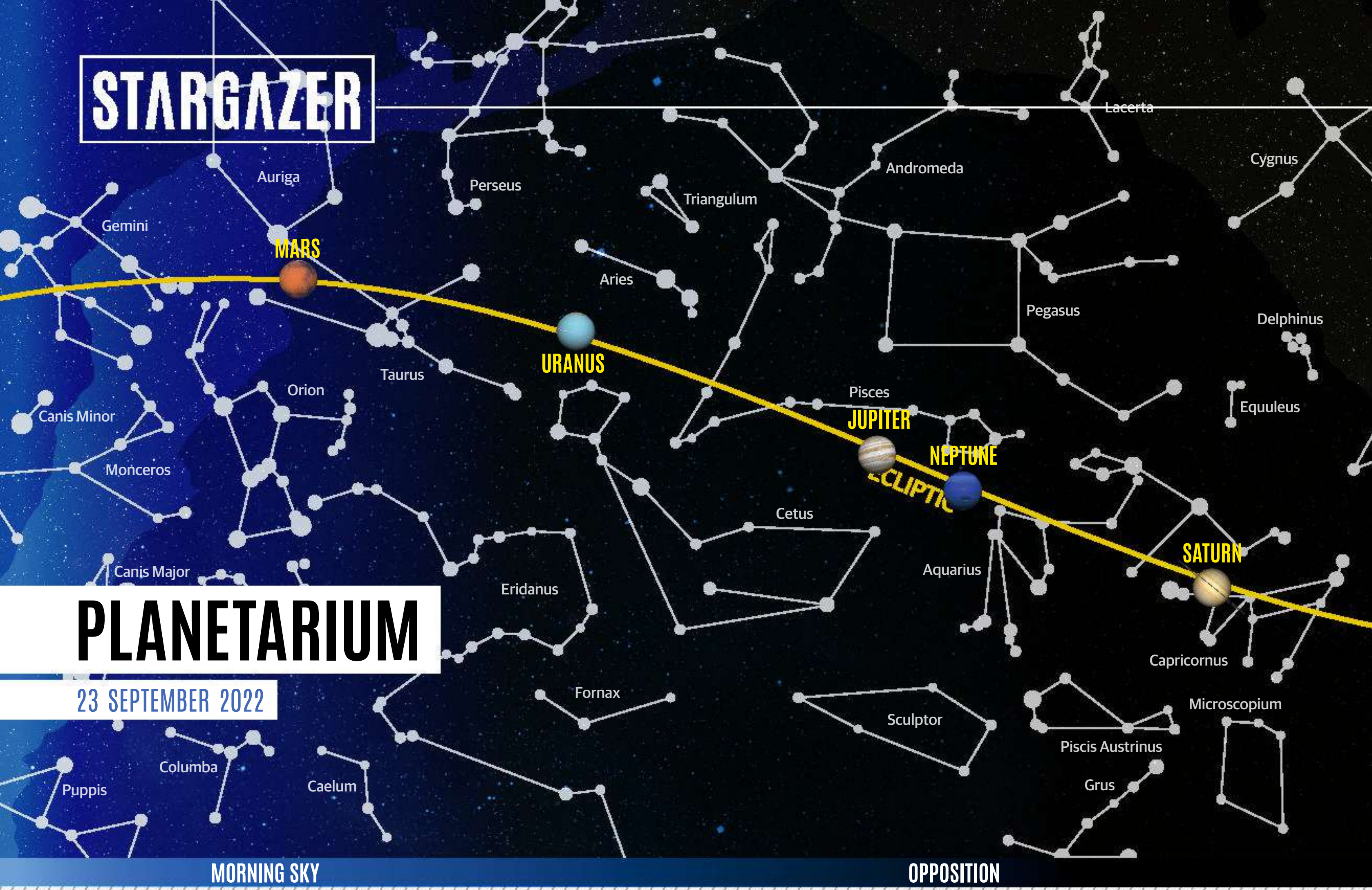
Greatest elongation

When the inner planets, Mercury and Venus, are at their maximum distance from the Sun. During greatest elongation, the inner planets can be observed as evening stars at greatest eastern elongation and as morning stars during western elongation.

© NASA/ESA; Source: Wikipedia Commons: Torben Hansen

PLANETARIUM

23 SEPTEMBER 2022


Auriga
Perseus
Triangulum
Andromeda
Lacerta
Cygnus
Gemini
MARS
Aries
Pegasus
Delphinus
URANUS
Taurus
Orion
Canis Minor
Pisces
JUPITER
Equuleus
NEPTUNE
ECLIPTIC
Monceros
Cetus
Aquarius
SATURN
Canis Major
Eridanus
Capricornus
Fornax
Sculptor
Microscopium
Piscis Austrinus
Columba
Puppis
Caelum
Grus
MORNING SKY
OPPOSITION

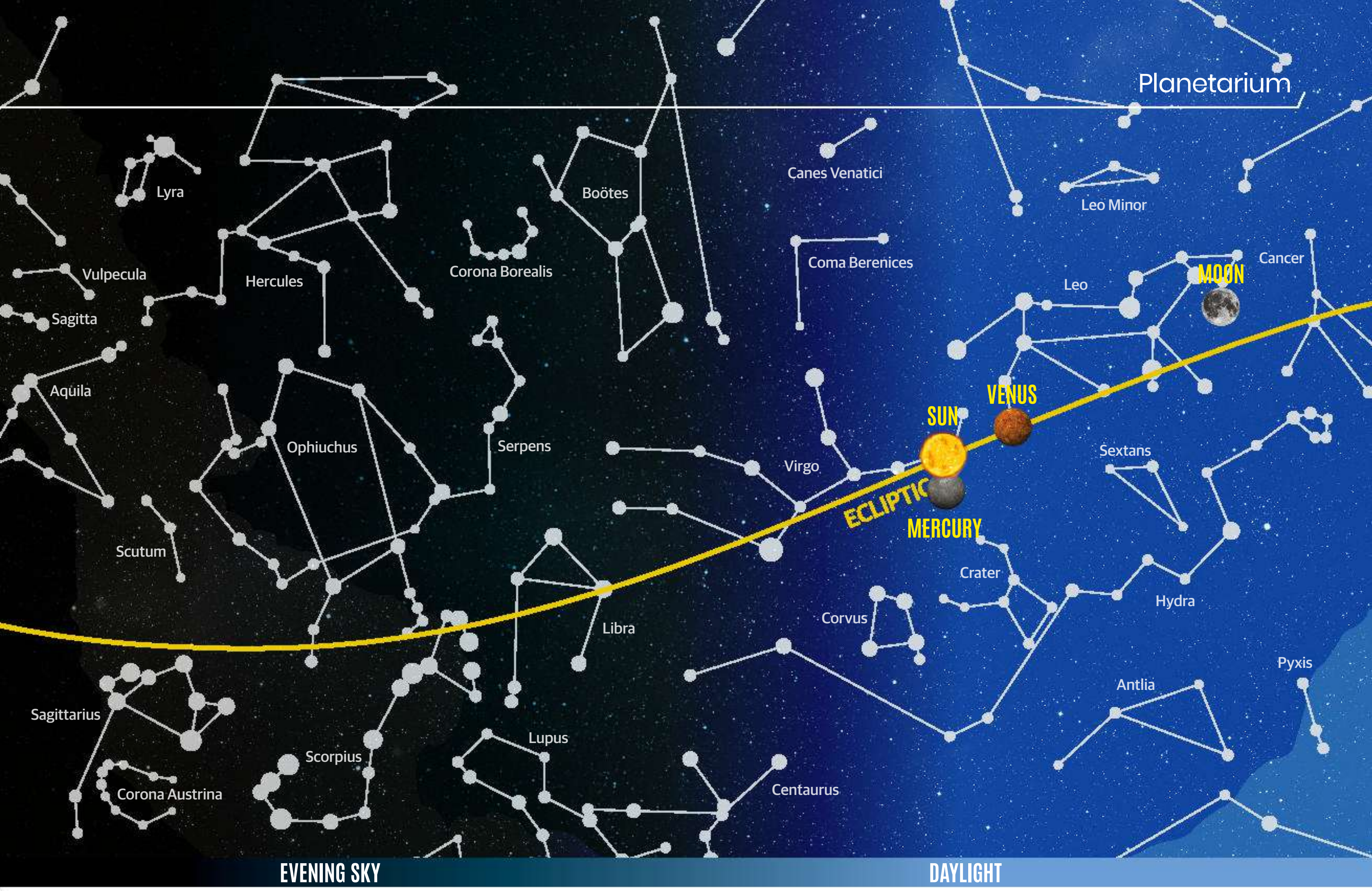
MOON CALENDAR

* The Moon does not pass the meridian on 9 September

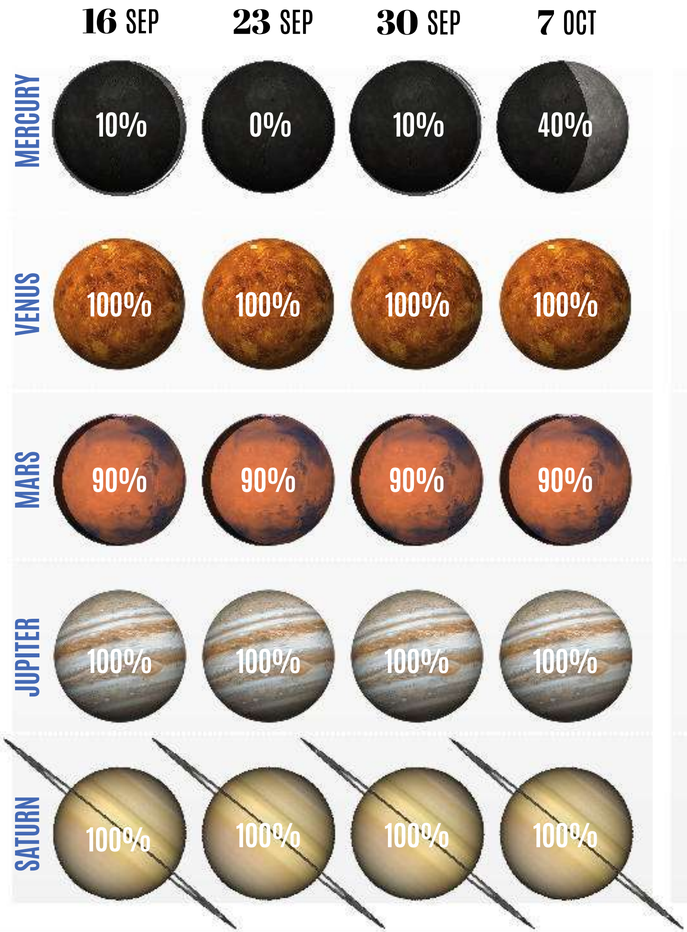
			8 SEP 96.9% ◒ 03:02 ◓ 19:20	**9** SEP --.--%* ◒ 04:33 ◓ 19:39	**10** SEP FM 99.6% ◒ 06:01 ◓ 19:55	**11** SEP 99.4% ◒ 07:26 ◓ 20:09
12 SEP 96.5% ◒ 08:48 ◓ 20:23	**13** SEP 91.3% ◒ 10:08 ◓ 20:37	**14** SEP 84.2% ◒ 11:26 ◓ 20:53	**15** SEP 75.8% ◒ 12:43 ◓ 21:13	**16** SEP 66.5% ◒ 13:58 ◓ 21:39	**17** SEP TQ 56.7% ◒ 15:07 ◓ 22:14	**18** SEP 46.9% ◒ 16:06 ◓ 22:59
19 SEP 37.2% ◒ 16:55 ◓ 23:55	**20** SEP 28.0% ◒ 17:32 ◓ --:--	**21** SEP 19.7% ◓ 01:01 ◒ 18:00	**22** SEP 12.4% ◓ 02:12 ◒ 18:21	**23** SEP 6.5% ◓ 03:27 ◒ 18:38	**24** SEP 2.4% ◓ 04:41 ◒ 18:52	**25** SEP NM 0.3% ◓ 05:57 ◒ 19:04
26 SEP 0.5% ◓ 07:13 ◒ 19:17	**27** SEP 3.0% ◓ 08:31 ◒ 19:30	**28** SEP 8.0% ◓ 09:51 ◒ 19:45	**29** SEP 15.3% ◓ 11:15 ◒ 20:05	**30** SEP 24.5% ◓ 12:40 ◒ 20:32	**1** OCT 35.3% ◓ 14:03 ◒ 21:11	**2** OCT 47.0% ◓ 15:16 ◒ 22:05
3 OCT FQ 58.9% ◓ 16:14 ◒ 23:17	**4** OCT 70.4% ◓ 16:55 ◒ --:--	**5** OCT 80.6% ◒ 00:40 ◓ 17:24	**6** OCT 89.1% ◒ 02:08 ◓ 17:45			

%	Illumination
◓	Moonrise time
◒	Moonset time
FM	Full Moon
NM	New Moon
FQ	First quarter
TQ	Third quarter

All figures are given for 00h at midnight (local times for London, UK)


Lyra
Boötes
Canes Venatici
Leo Minor
Vulpecula
Hercules
Corona Borealis
Coma Berenices
Cancer
MOON
Leo
Sagitta
Aquila
VENUS
SUN
Ophiuchus
Serpens
Virgo
Sextans
ECLIPTIC
MERCURY
Scutum
Crater
Corvus
Hydra
Libra
Pyxis
Antlia
Sagittarius
Lupus
Scorpius
Centaurus
Corona Austrina
EVENING SKY
DAYLIGHT

ILLUMINATION PERCENTAGE



PLANET POSITIONS

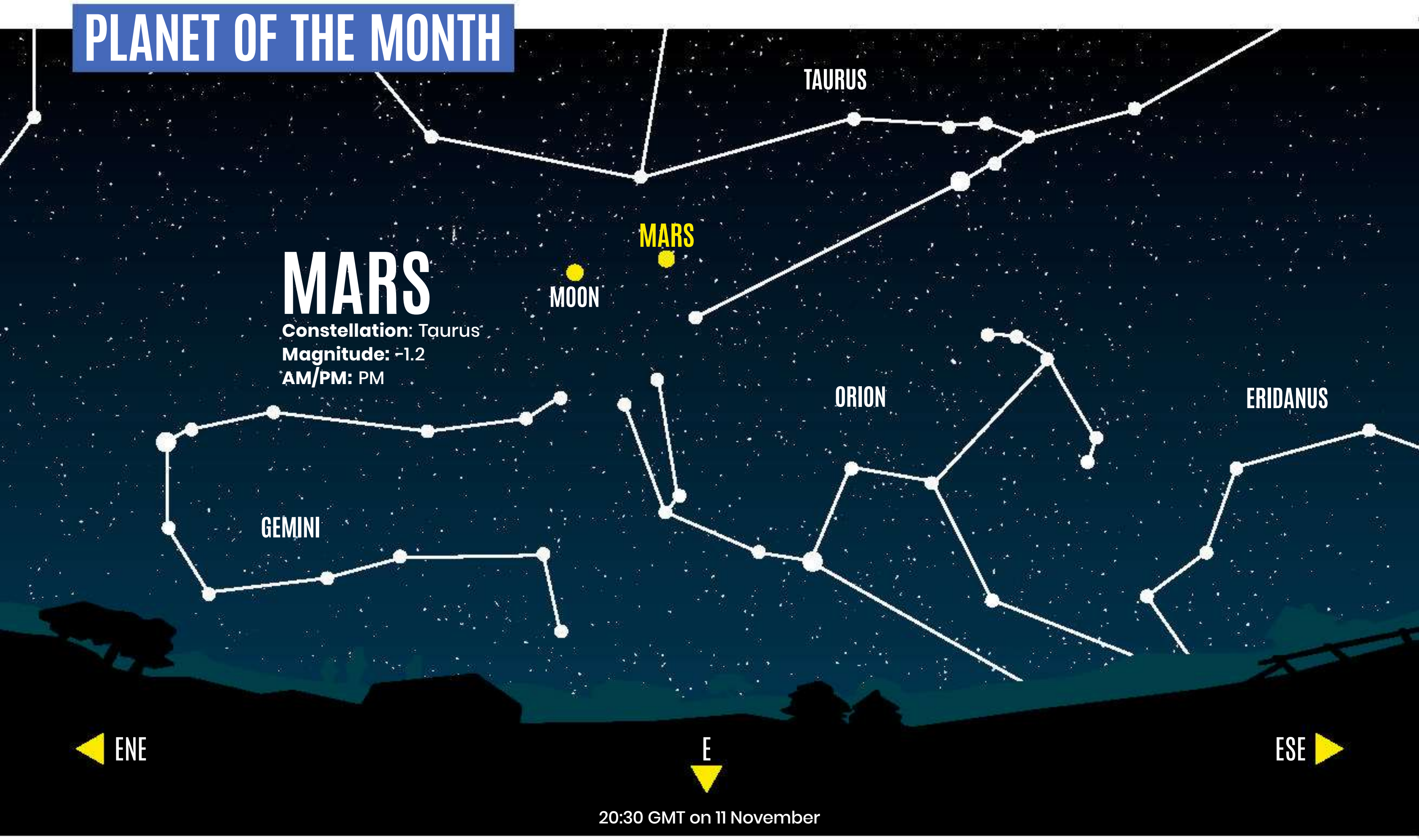
All rise and set times are given in BST

DATE	RA	DEC	CONSTELLATION	MAG	RISE	SET
8 SEP	12h 23m 57s	-06° 38' 25"	Virgo	+ 0.6	08:47	19:48
16 SEP	12h 18m 17s	-06° 26' 24"	Virgo	+2.3	08:06	19:08
23 SEP	11h 56m 09s	-02° 47' 18"	Virgo	+5.7	06:58	18:37
30 SEP	11h 38m 14s	+02° 47' 55"	Virgo	-0.3	05:24	17:59
7 OCT	11h 46m 00s	+02° 47' 55"	Virgo	-0.3	05:24	17:59
8 SEP	10h 22m 20s	+11° 30' 39"	Leo	-3.9	05:09	19:15
16 SEP	10h 59m 50s	+07° 54' 48"	Leo	-3.9	05:34	19:02
23 SEP	11h 32m 08s	+04° 33' 48"	Leo	-3.9	05:56	18:50
30 SEP	12h 04m 11s	+01° 05' 49"	Virgo	-3.9	06:18	18:37
7 OCT	12h 36m 11s	-02° 24' 52"	Virgo	-3.9	06:40	18:23
8 SEP	04h 33m 41s	+20° 45' 29"	Taurus	-0.2	22:26	14:23
16 SEP	04h 49m 54s	+21° 25' 51"	Taurus	-0.3	22:06	14:12
23 SEP	05h 02m 47s	+21° 55' 26"	Taurus	-0.4	21:48	14:01
30 SEP	05h 14m 11s	+22° 20' 40"	Taurus	-0.6	21:29	13:48
7 OCT	05h 23m 50s	+22° 42' 42"	Taurus	-0.7	21:09	13:32
8 SEP	00h 23m 47s	+00° 50' 08"	Pisces	-2.9	20:08	08:23
16 SEP	00h 20m 12s	+00° 25' 53"	Pisces	-2.9	19:35	07:46
23 SEP	00h 16m 51s	+00° 03' 36"	Pisces	-2.9	19:06	07:14
30 SEP	00h 13m 25s	-00° 18' 48"	Pisces	-2.9	18:37	06:41
7 OCT	00h 10m 02s	-00° 40' 29"	Pisces	-2.9	18:07	06:08
8 SEP	21h 30m 47s	-16° 06' 43"	Capricornus	+0.4	18:40	03:58
16 SEP	21h 28m 54s	-16° 15' 50"	Capricornus	+0.4	18:08	03:24
23 SEP	21h 27m 28s	-16° 22' 33"	Capricornus	+0.5	17:39	02:54
30 SEP	21h 26m 17s	-16° 27' 57"	Capricornus	+0.5	17:11	02:25
7 OCT	21h 25m 23s	-16° 31' 54"	Capricornus	+0.5	16:43	01:56

THIS MONTH'S PLANETS

Mars continues to dazzle, making it an easy target for evening observers

PLANET OF THE MONTH



MARS

Constellation: Taurus
Magnitude: -1.2
AM/PM: PM

20:30 GMT on 11 November

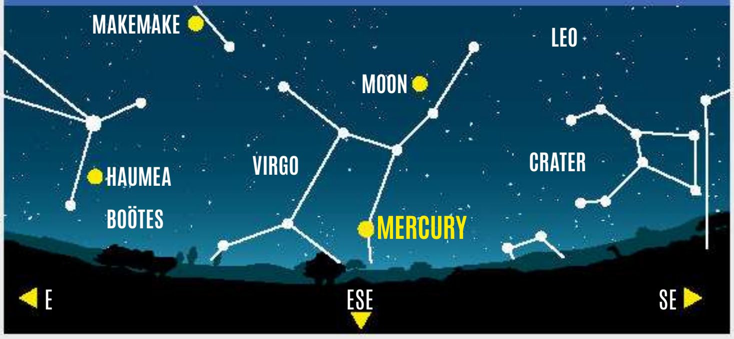
Mars is our planet of the month again because it is now really starting to brighten in advance of it reaching opposition at the end of the year. Then it will be so close to Earth – and so well placed in the night sky – that it will be strikingly obvious to even the most inexperienced sky-watcher. But if you track it down now, make yourself familiar with the part of the sky it is in and how it is moving – if you do, you'll enjoy that opposition show a lot more.

At the start of our observing period Mars will rise around 20:45 and will be found shining in the zodiacal constellation of Taurus, where it seems to have been embedded for months now. Although Mars is famously known as the Red Planet, it is actually more of an orange colour to the naked eye – more topaz than ruby if you know your gemstones. Shining at magnitude -0.8, it will be clearly visible to the naked eye, brighter than any star in its part of the sky and visible all through the night as Earth's rotation sweeps it from east to west.

As the days pass Mars will drift further eastwards through Taurus, and its brightness will slowly increase as it grows ever closer to Earth. By the end of October Mars will have stopped moving eastwards and will begin to move westwards again, turning the corner of its racetrack in the sky towards opposition. Having moved away from them over the past month, it will now head back towards two of the largest and most famous star clusters in the sky – the Pleiades and the Hyades. By now it will have brightened to magnitude -1.2, so bright you won't be able to miss it.

By 11 November Mars will have brightened to magnitude -1.5, making it a strikingly bright object that will really draw the eye. By that date Mars will be rising before 18:00 and will become visible low in the northeast as soon as twilight is deep enough to see stars. Despite looking so bright to the eye, a small telescope will still only show it as a wobbly, blurry orange disc. A larger telescope will let you see dark features on its surface and maybe the blue-white spot of one of its polar ice caps.

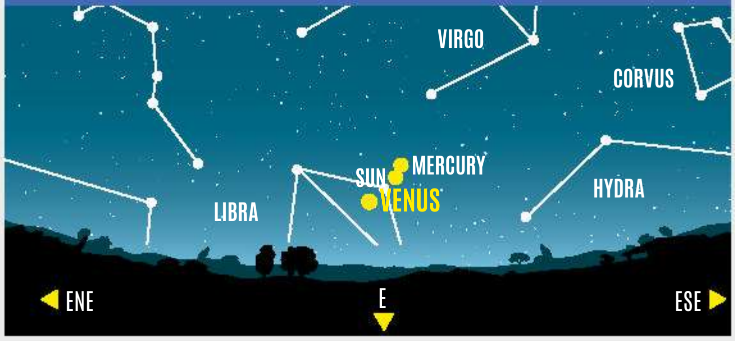
MERCURY 07:00 BST on 23 October


MAKEMAKE
LEO
MOON
HAUMEA
VIRGO
CRATER
BOÖTES
MERCURY
E
ESE
SE

Constellation: Virgo **Magnitude:** -0.17 **AM/PM:** AM

At the start of our observing period Mercury is a tiny copper-hued star shining in Virgo before dawn, rising around two hours before the Sun. It will be an easy naked-eye object if your eastern horizon is flat and low, but Mercury's low altitude will mean it might be hidden by any trees or buildings you have in that direction.

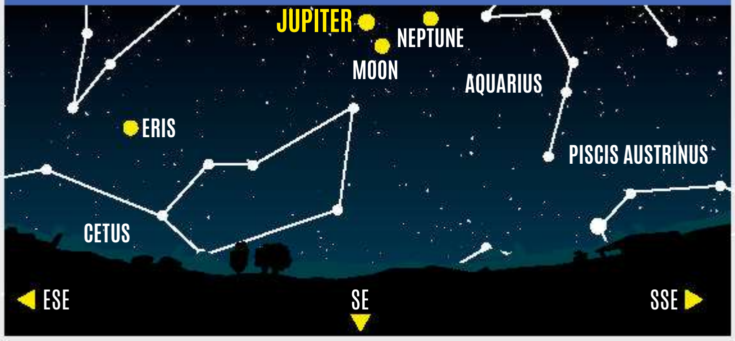
VENUS 08:00 GMT on 6 November


VIRGO
CORVUS
SUN
MERCURY
VENUS
HYDRA
LIBRA
ENE
E
ESE

Constellation: Virgo **Magnitude:** -3.9 **AM/PM:** AM

At the start of our observing period Venus will be rising barely a quarter of an hour before the Sun, so you might glimpse it in binoculars very low in the morning twilight as the sky turns from blue to gold. However, it's very unlikely, as the brightness of the sky will overwhelm the planet's brightness.

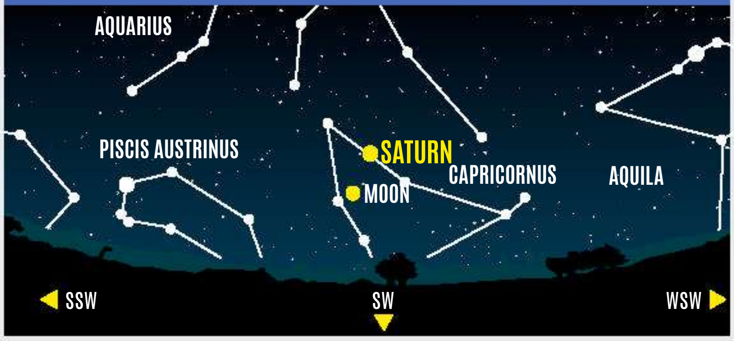
JUPITER 19:00 GMT on 4 November


JUPITER
NEPTUNE
MOON
AQUARIUS
ERIS
PISCIS AUSTRINUS
CETUS
ESE
SE
SSE

Constellation: Pisces **Magnitude:** -2.9 **AM/PM:** PM

This will be a great month if you enjoy seeing the largest planet in the Solar System. At the start of our observing period Jupiter will be rising just as the Sun is setting, clearly visible to the naked eye as a bright blue-white 'star' low in the east as twilight falls. It won't set until 06:00, giving you the whole night to enjoy it.

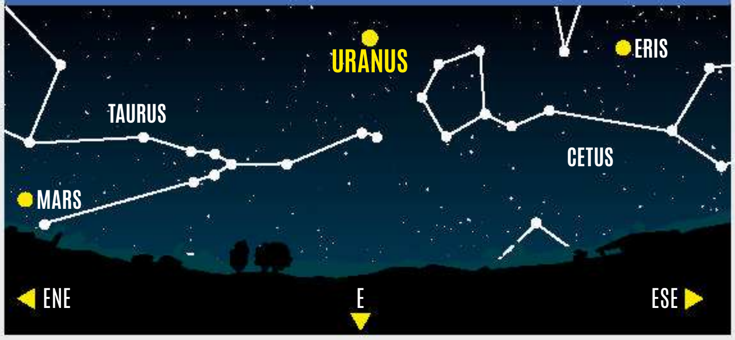
SATURN 22:00 GMT on 1 November


AQUARIUS
PISCIS AUSTRINUS
SATURN
MOON
CAPRICORNUS
AQUILA
SSW
SW
WSW

Constellation: Capricornus **Magnitude:** +0.6 **AM/PM:** PM

At the start of our observing period Saturn will already be shining low in the southeast as the sky darkens, at its highest around 21:00, almost due south. It will be setting in the early hours, so your best views will come before midnight when it is high enough to not be dimmed by the murk and haze that lingers above the horizon.

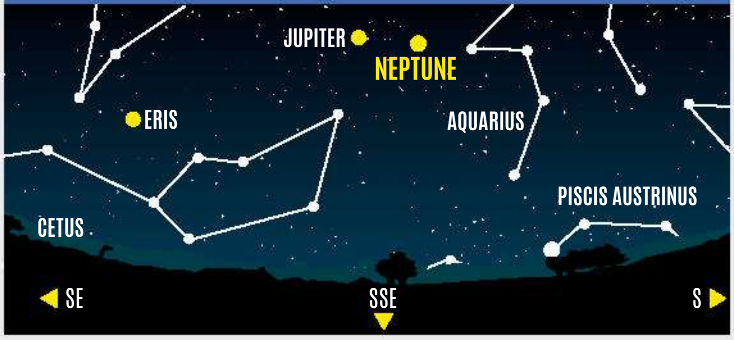
URANUS 19:45 GMT on 1 November


URANUS
ERIS
TAURUS
CETUS
MARS
ENE
E
ESE

Constellation: Aries **Magnitude:** +5.8 **AM/PM:** PM

Uranus will be rising at around 19:00 at the start of our observing period and at its highest in the sky by 23:00. By mid-November this distant, icy world will be rising at 16:00 and will be visible all through the night. The waxing gibbous Moon will be to Uranus' right on the evening of 7 November and to its left the following night.

NEPTUNE 19:45 GMT on 1 November


JUPITER
NEPTUNE
ERIS
AQUARIUS
PISCIS AUSTRINUS
CETUS
SE
SSE
S

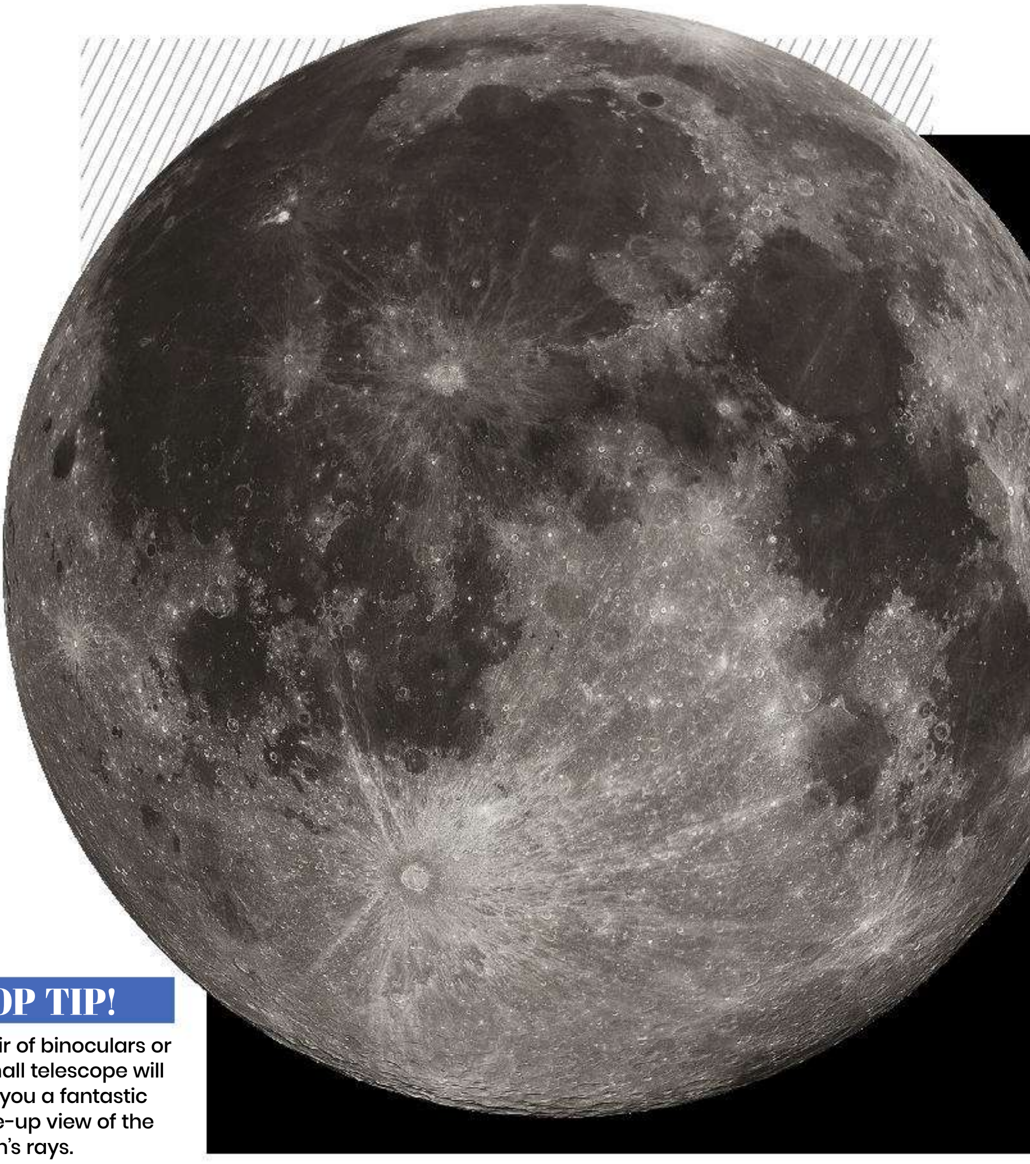
Constellation: Aquarius **Magnitude:** +7.8 **AM/PM:** PM

At the start of our observing period Neptune will be rising before sunset, making it visible all through the night. With a magnitude of +7.8 it is far too faint to be visible to the naked eyes. If you are determined to track it down you'll need a small telescope, and even then it will only look like a faint blue-hued 'star'.

MOON TOUR

LUNAR RAYS

This month's full Moon affords you the opportunity to spot a unique feature



© NASA

TOP TIP!

A pair of binoculars or a small telescope will give you a fantastic close-up view of the Moon's rays.

Astronomers are often asked when the best time to look at the Moon is. If you're wanting to see details then full Moon is the worst time. To see the Sun-drenched peaks of its towering mountains, the frigid depths of its deepest craters and the floors of the valleys which weave across its surface, you need to be looking when the Moon is a crescent, or quarter phase. With the Sun's rays hitting those geological landmarks at an angle, it will cast stark shadows behind them and they will stand out in amazing clarity. However, full Moon is the best time to see the Moon's rays – long, bright lines that appear to have been painted on its surface.

Lunar rays are actually long trails of rocky and dusty debris that were sprayed across the Moon by the cataclysmic impacts which formed some of its largest and youngest craters. When the Moon is full even your naked eye is powerful enough to show you the rays that surround and stretch away from four of the nearside's most famous and attractive craters.

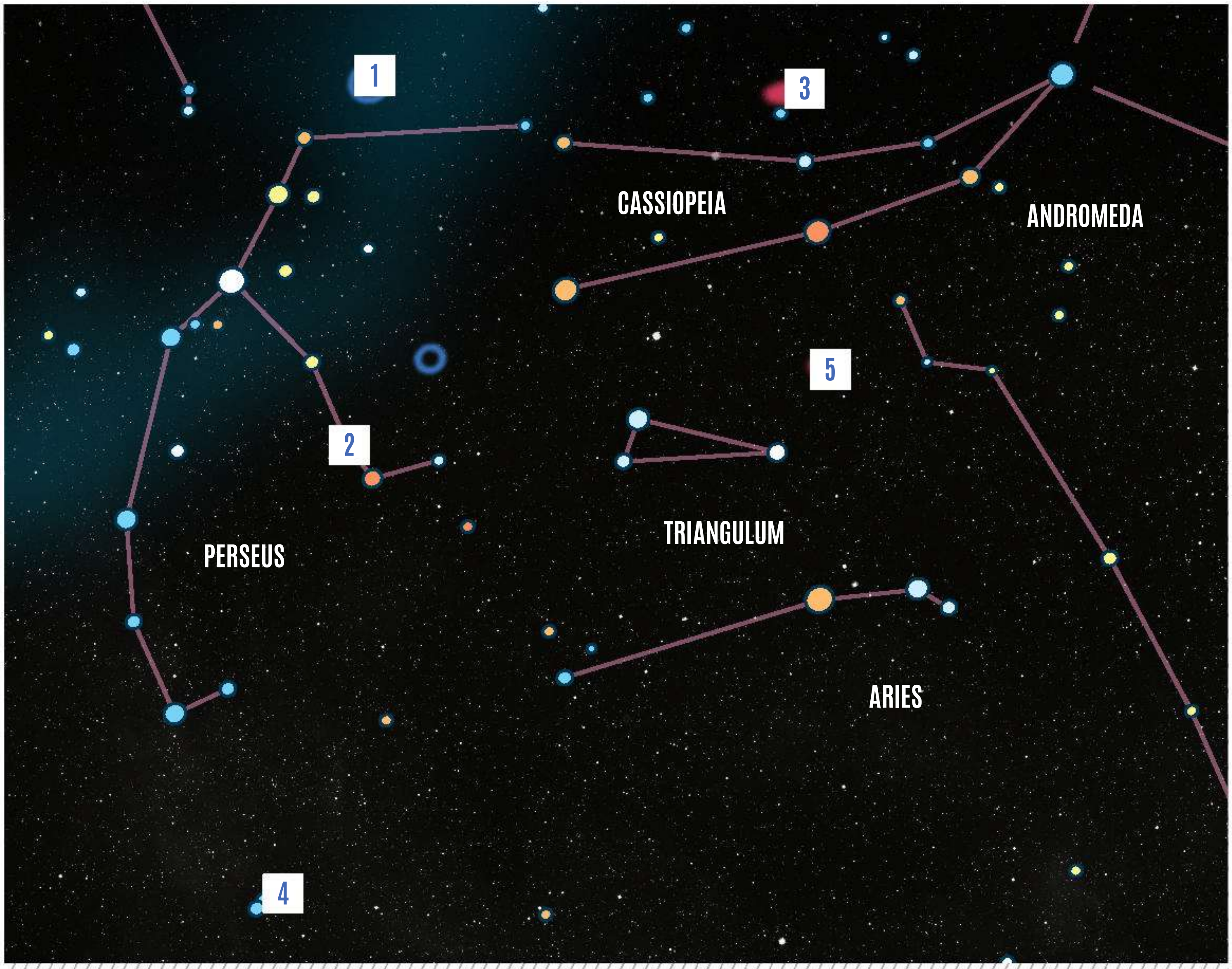
But how do they form? Imagine you're standing on the Moon millions of years ago. Suddenly, without warning, an asteroid slams into the Moon. After the blinding flash you'd see a huge plume of dust rising up into the sky, and fires raging beneath it. After a short time you would find yourself under a hail of rocks – big and small – debris from the impact. Cowering and looking up at the sky, you would see a long streamer of debris arcing across it, falling down to the surface to leave behind a long, light-coloured line of pulverised rock and dust, or a lunar ray.

The full Moon, which falls on 10 September and again on 9 October, offers great views of the ray systems surrounding four of the most famous lunar craters. All of these can be seen with the naked eye, not just when the Moon is full but when it is new, too, when no or very little sunlight is bathing it and it is lit by a ghostly light reflecting off the Earth, known as Earthshine. Total lunar eclipses also offer great opportunities for a Moon observer to view some rays, bathed in a beautiful ruddy glow.

The largest system of rays surrounds the great crater Tycho. Tycho lies down near the bottom of the Moon's disc and was formed around 800 million years ago. Looking up at the Moon on that fateful day, the prehistoric life roaming Earth at the time would have seen a bright flash as a chunk of space rock ten kilometres (6.2 miles) wide slammed into the Moon, blasting out a crater 85 kilometres (53 miles) wide and almost five kilometres (three miles) deep. Huge amounts of debris splashed out by the impact fell in long lines across the lunar landscape, leaving bright rays up to 1,500 kilometres (932 miles) in length behind. Those ancient creatures are long gone, but today we can see Tycho's rays radiating away from it for incredible distances.

To the upper left of Tycho, to the top left of the Moon's face, lies a trio of bright, young craters with ray systems that are all obvious to the naked eye. The largest of the three, Copernicus, is nicknamed 'the Monarch of the Moon' because of its impressive size, and this 96-kilometre (60-mile) wide and four-kilometre (2.5-mile) deep crater is surrounded by a very obvious system of rays – the longest of which stretch for 800 kilometres (497 miles).

To Copernicus' left lies the smaller crater Kepler. Despite being only 29 kilometres (18 miles) across, Kepler is easily seen by the naked eye as a bright spot in the centre of a very striking spray of bright rays. Above and to the left of Kepler, close to the Moon's limb, is Aristarchus. With a diameter of 40 kilometres (25 miles) it is actually larger than Kepler, but it appears smaller due to its proximity to the limb. Aristarchus has a small spray of bright rays to its southeast.



NAKED EYE AND BINOCULAR TARGETS

On crisp autumn nights find galaxies, beautiful star clusters and a demonic star

1 The Double Cluster (NGC 869 and NGC 884)

Look between Cassiopeia and Perseus on a clear night and you'll sense a misty smudge of light at the corner of your eye. Binoculars show this is a pair of star clusters so close together they're almost touching. But the 'Double Cluster' is misleadingly named – one cluster is twice as far away as the other.

2 Algol (Beta Persei)

Between the Double Cluster and the Pleiades shines Algol, the second-brightest star in Perseus. It's a blue-white variable star that appears to brighten and fade every three days. Algol's nickname, 'the Demon Star', is very appropriate, as it represents an eye winking in the severed head of the Gorgon Medusa.

3 Andromeda Galaxy (Messier 31)

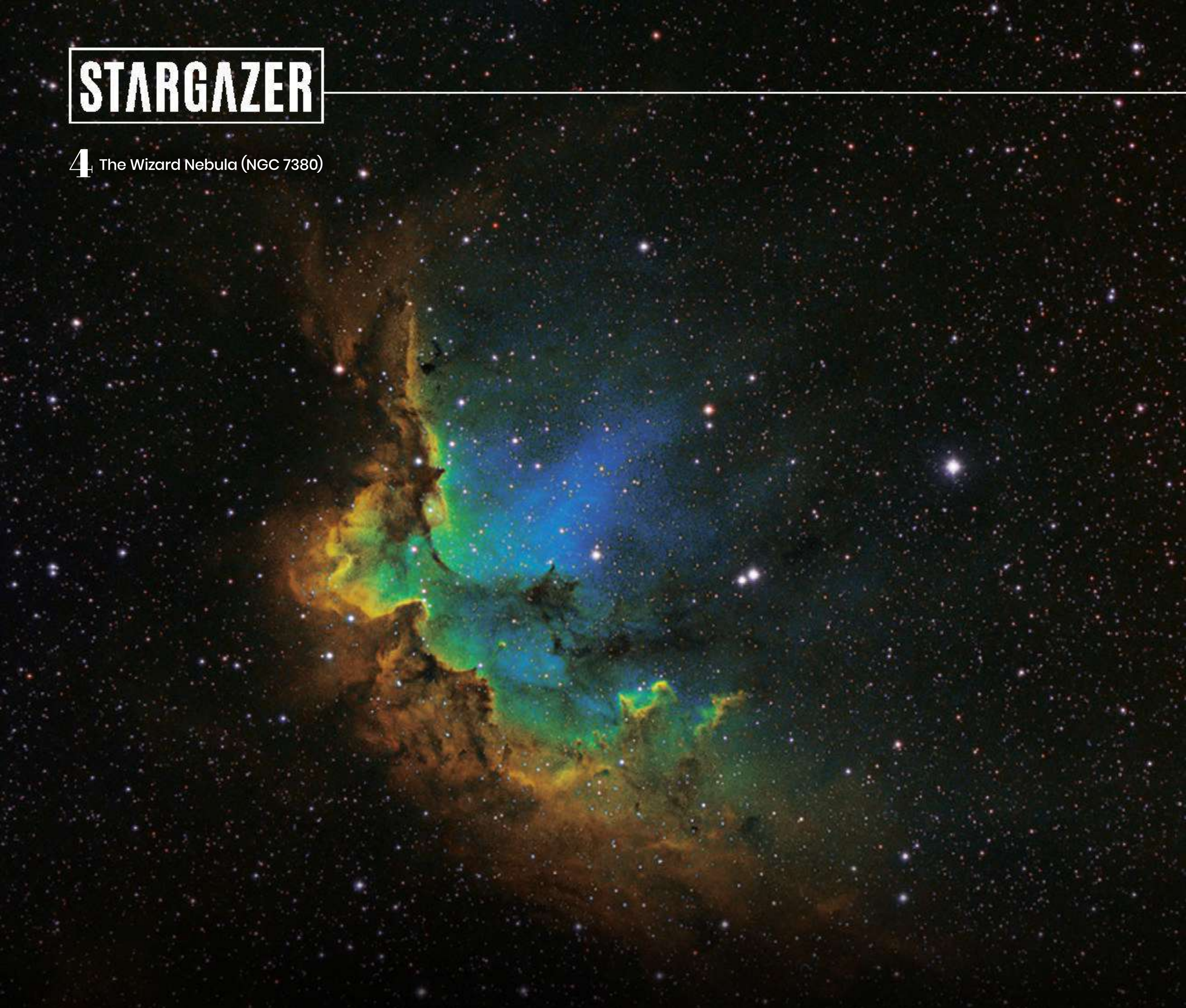
If you have good eyesight you will see a misty smudge out of the corner of your eye between the Double Cluster and the Square of Pegasus. Binoculars show the Andromeda Galaxy as a lens-shaped smear of light about as wide as the full Moon that glows at a magnitude of +3.44.

4 The Pleiades (Messier 45)

Known as a winter object, the Pleiades star cluster can be spotted low in the sky after dark this month. To the naked eye, Messier 45 – also dubbed the Seven Sisters – looks like a fingernail-sized knot of stars. Binoculars show it as a beautiful spill of blue-white diamonds in the shape of a mini Big Dipper.

5 Triangulum Galaxy (Messier 33)

Although it's technically bright enough to see with the naked eye, Messier 33 isn't anywhere near as large or as obvious as Messier 31. However, on the clearest Moon-free night this spiral galaxy is visible, appearing as a small, misty patch in 10x50 binoculars from 3 million light years away.



4 The Wizard Nebula (NGC 7380)

DEEP SKY CHALLENGE

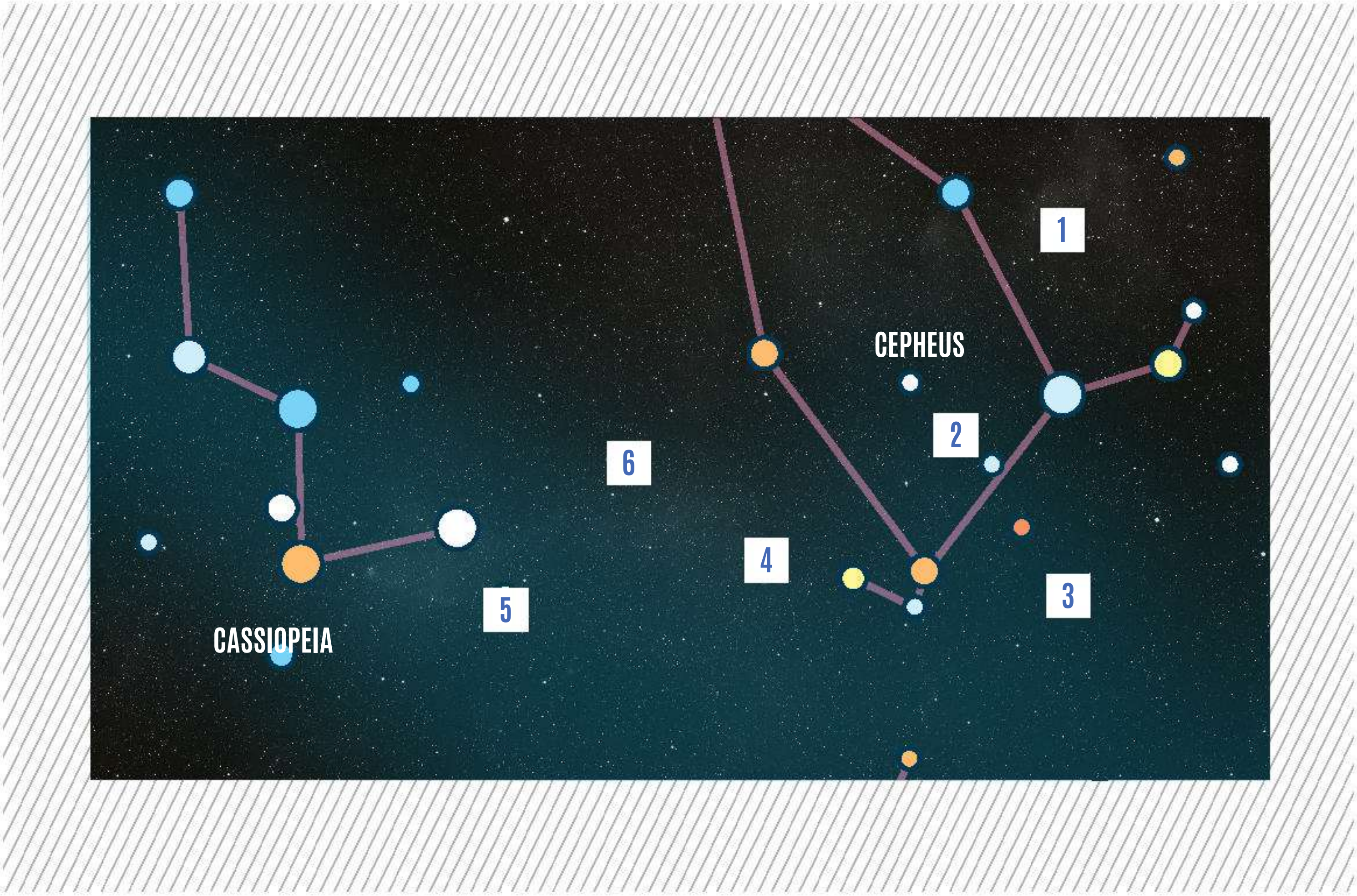
TREASURES OF THE AUTUMN MILKY WAY

Among the richest for deep-sky observers, September brings star clusters, nebulae and galaxies galore

The Milky Way, that ribbon of light which is part of a spiral arm of our own galaxy, is still well on show during late September and early October. This means that a lot of deep-sky objects either embedded in it or near to it are also on display.

High up in the sky from mid-northern latitudes, the constellations of Cepheus (the King) and Cassiopeia (the Vain Queen) can be found sweeping around the north celestial pole throughout the course of the night. The pair of royal star patterns are full of star clusters and nebulae easily available to even the most modest of amateur telescopes. Within this region of sky there are some challenges for those with telescopes with even larger apertures. The Elephant's Trunk Nebula (IC 1396), for example, has a star cluster associated with the nebula which is relatively easy to see, but it's the surrounding gas and dust that's much more challenging. Whatever you choose to look at, you can enjoy the delights of the early autumn skies.

6 Messier 52



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1 The Iris Nebula (NGC 7023)

A bright reflection nebula lit up to magnitude +6.8 by a star cluster at its centre, it requires an instrument with an aperture of at least ten inches to pick out details beyond a faint, misty patch.

2 NGC 7160

A small but attractive open star cluster, NGC 7160 can be picked up under moderate magnification. The cluster is quite sparse. However, its member stars are noticeably bright-white diamonds.

3 Elephant's Trunk Nebula (IC 1396)

If you look carefully through your telescope of at least a medium to large-sized aperture, you can locate a dark, dense globule known as IC 1396A which gives the nebula its name.

4 The Wizard Nebula (NGC 7380)

Here's another tricky-to-spot nebula with a small star cluster nestled at the centre. In order to pick out the details of the Wizard Nebula, it's likely that you'll need a filter, such as an OIII.

5 Caroline's Rose (NGC 7789)

This lovely star cluster does look like a rose seen from above. It's located among the rich starfields of the Milky Way towards Cassiopeia, so will require a trained eye and telescope in order to spot it.

6 Messier 52

In the constellation of Cassiopeia is this large open star cluster that's easy to locate in even a small-aperture telescope thanks to its magnitude of +5.0 and its location in the 'W'.

1 The Iris Nebula (NGC 7023)

THE NORTHERN HEMISPHERE

The longer nights are upon us, so enjoy both Solar System and deep-sky objects

The autumn skies are starting to wheel into view, offering a wonderful selection of galaxies, open and globular star clusters for those with binoculars or telescopes. Globular clusters including the Great Globular Cluster in Hercules (Messier 13) and Messier 56 in Lyra (the Harp), as well as open cluster IC 4665 in Ophiuchus (the Serpent-bearer), are splendid evening targets. If you're keen to stay up until the early hours of the morning, you'll be rewarded as Taurus' Pleiades star cluster (Messier 45) and galaxies such as the Andromeda Galaxy (Messier 31), nearby Triangulum Galaxy (Messier 33) and face-on spiral Messier 74 in the constellation Pisces (the Fishes) make their appearance.

Using the sky chart

This chart is for use at 22:00 mid-month and is set for 52 degrees latitude.

1 Hold the chart above your head with the bottom of the page in front of you.

2 Face south and notice that north on the chart is behind you.

3 The constellations on the chart should now match what you see in the sky.

Magnitudes

- Sirius (-1.4)
- -0.5 to 0.0
- 0.0 to +0.5
- +0.5 to +1.0
- +1.0 to +1.5
- +1.5 to +2.0
- +2.0 to +2.5
- +2.5 to +3.0
- +3.0 to +3.5
- +3.5 to +4.0
- +4.0 to +4.5
- Fainter
- Variable star

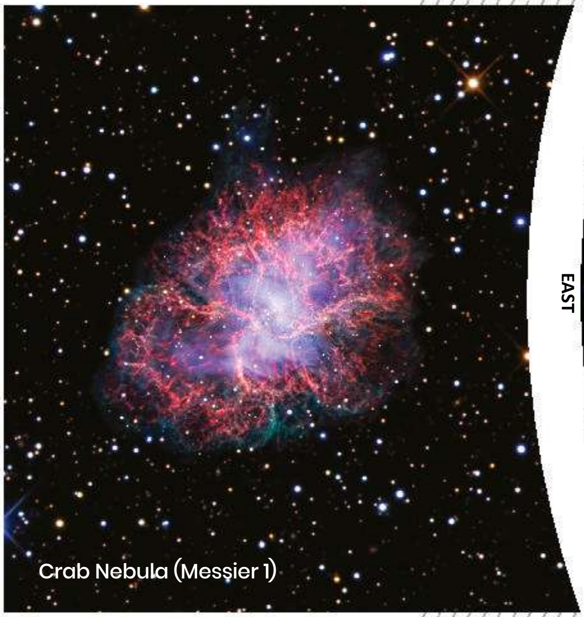
Spectral types

- O-B
- A
- F
- G
- K
- M

Deep-sky objects

- Open star clusters
- Globular star clusters
- Bright diffuse nebulae
- Planetary nebulae
- Galaxies

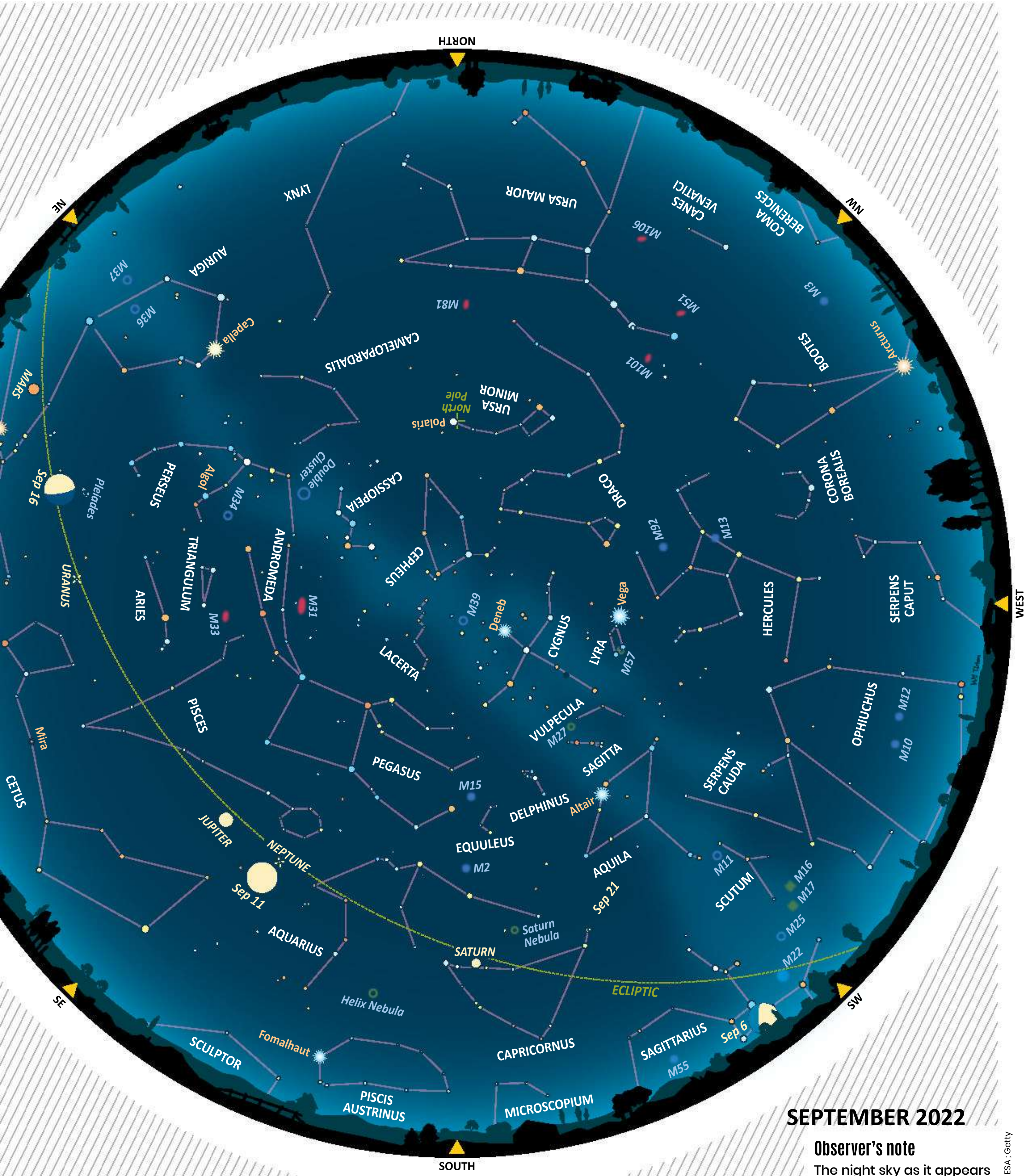
Messier 56



Crab Nebula (Messier 1)

The constellations of Auriga (the Charioteer) and Taurus (the Bull)

Aldebaran
TAURUS
EAST


NORTH
NE
NW
WEST
SE
SW
SOUTH
LYNX
URSA MAJOR
CANES VENATICI
COMA BERENICES
M106
AURIGA
M37
M36
Capella
M81
M51
M3
CAMELOPARDALIS
URSA MINOR
North Pole
Polaris
M101
BOOTES
Arcturus
MARS
Sep 16
Pleiades
PERSEUS
Algol
M34
Double Cluster
CASSIOPEIA
DRACO
CORONA BOREALIS
M92
M13
URANUS
ARIES
TRIANGULUM
M33
ANDROMEDA
M31
CEPHEUS
M39
Deneb
CYGNUS
LYRA
Vega
M57
HERCULES
SERPENS CAPUT
LACERTA
PISCES
VULPECULA
M27
OPHIUCHUS
M12
M10
Mira
CETUS
PEGASUS
SAGITTA
SERPENS CAUDA
M15
DELPHINUS
Altair
JUPITER
NEPTUNE
EQUULEUS
AQUILA
M11
M16
M17
Sep 11
M2
Sep 21
SCUTUM
M25
Saturn Nebula
AQUARIUS
SATURN
M22
ECLIPTIC
Helix Nebula
Sep 6
SAGITTARIUS
Fomalhaut
SCULPTOR
CAPRICORNUS
M55
PISCIS AUSTRINUS
MICROSCOPIUM

SEPTEMBER 2022

Observer's note

The night sky as it appears on 17 September 2022 at approximately 22:00 (BST)

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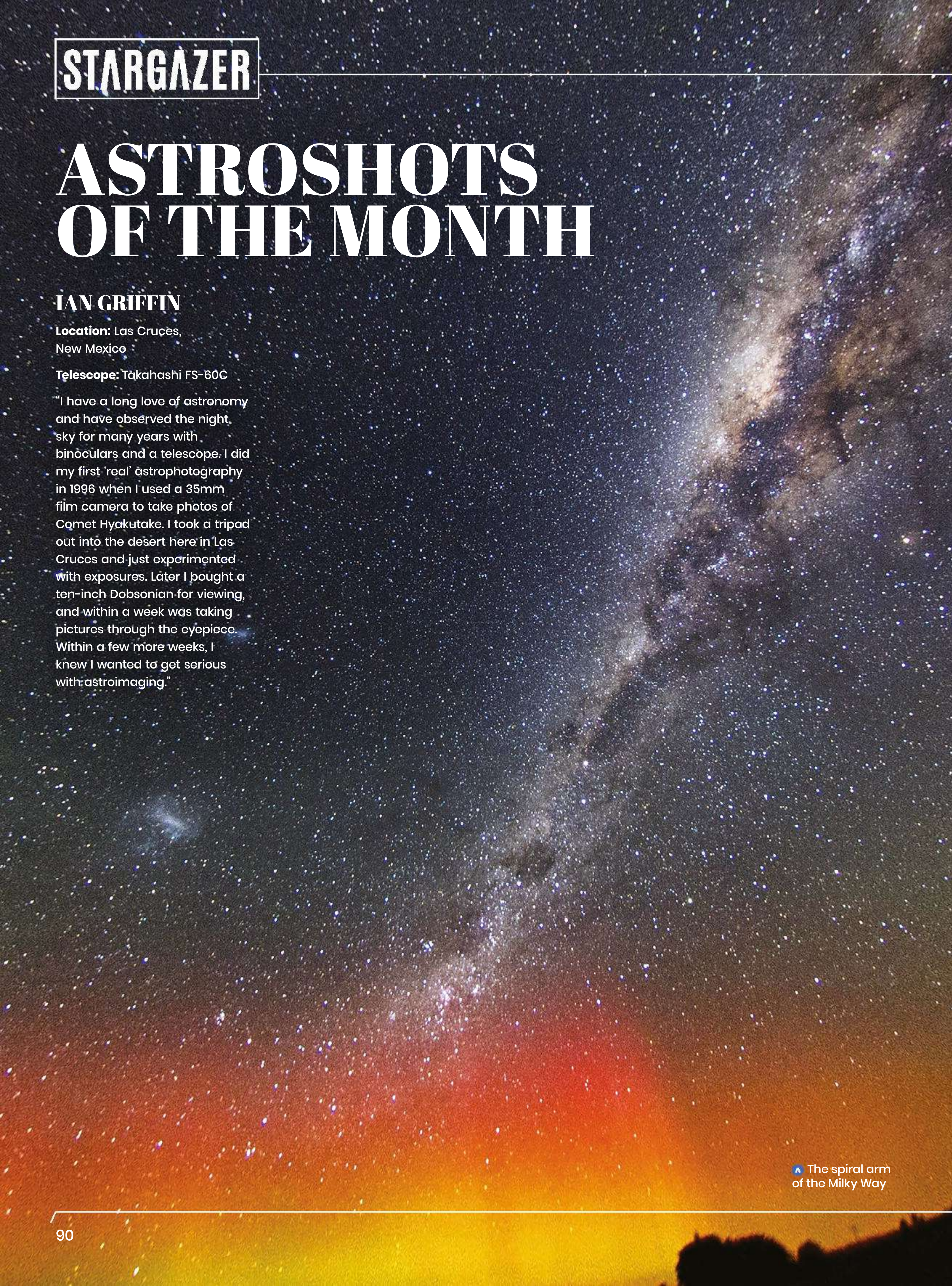
ASTROSHOTS OF THE MONTH



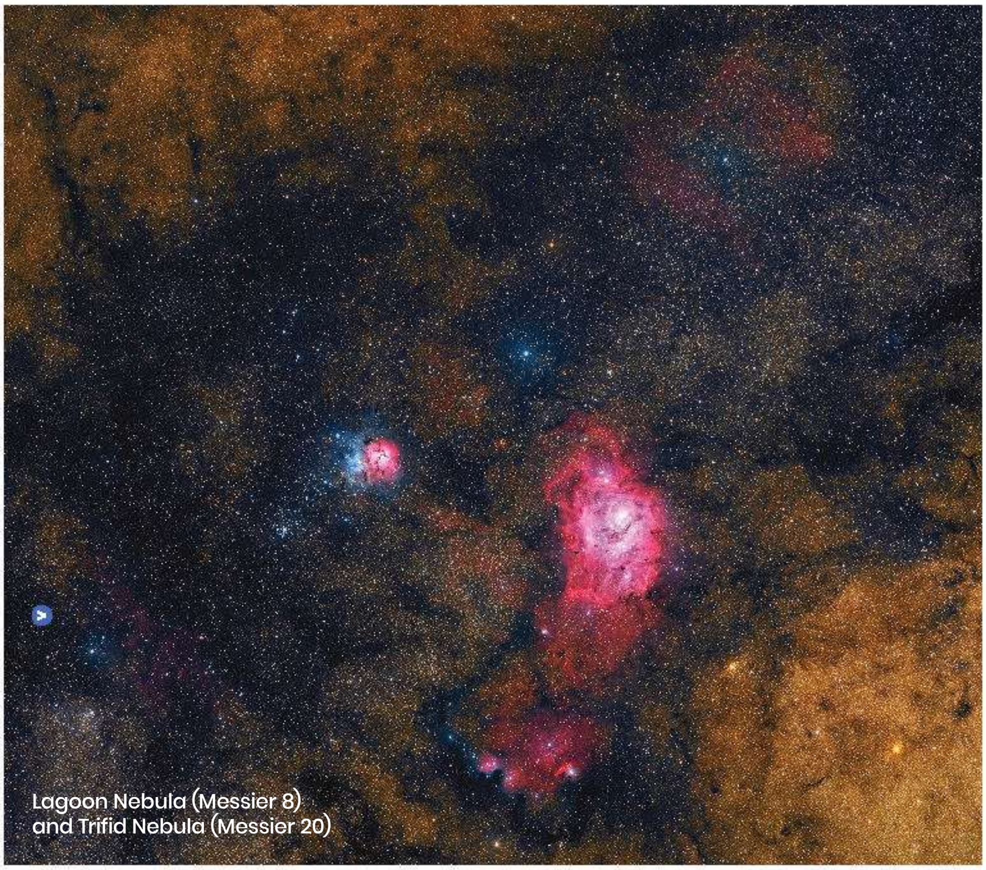
IAN GRIFFIN

Location: Las Cruces,
New Mexico

Telescope: Takahashi FS-60C

"I have a long love of astronomy and have observed the night sky for many years with binoculars and a telescope. I did my first 'real' astrophotography in 1996 when I used a 35mm film camera to take photos of Comet Hyakutake. I took a tripod out into the desert here in Las Cruces and just experimented with exposures. Later I bought a ten-inch Dobsonian for viewing, and within a week was taking pictures through the eyepiece. Within a few more weeks, I knew I wanted to get serious with astroimaging."

The spiral arm of the Milky Way



Lagoon Nebula (Messier 8) and Trifid Nebula (Messier 20)

BASUDEB CHAKRABARTI

Location: Heaven's Mirror Observatory, Australia

Telescope: Takahashi FSQ-106ED

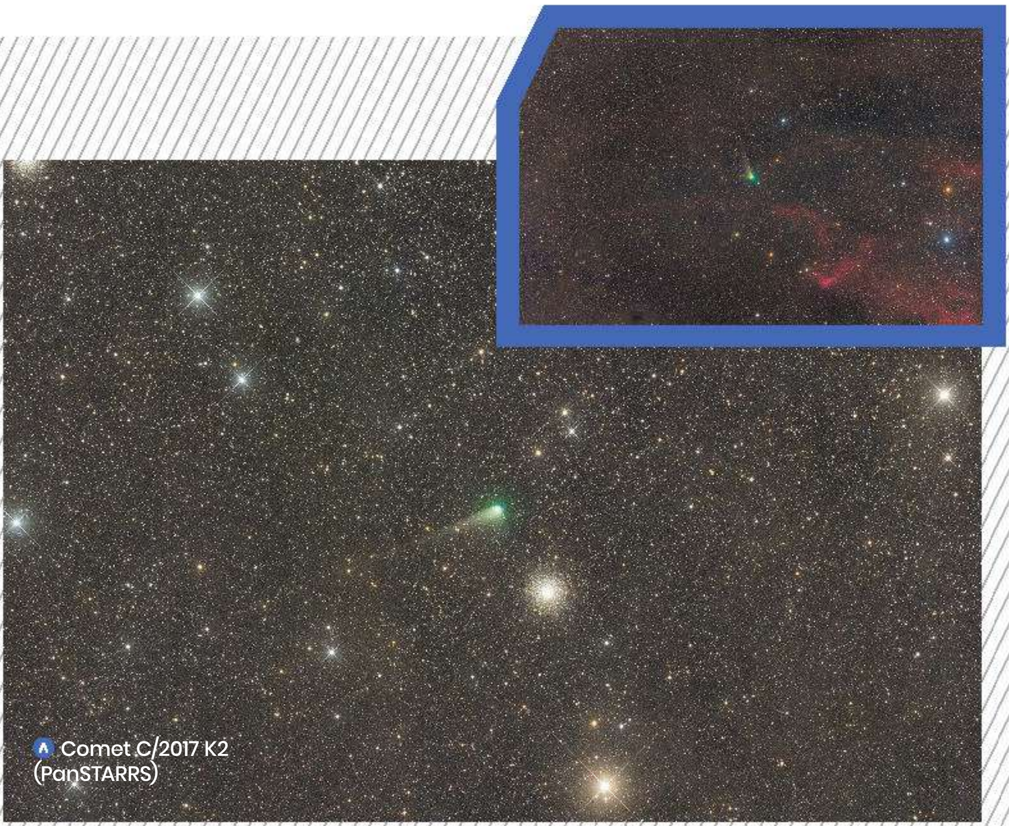
"The Lagoon and Trifid Nebula are a giant interstellar cloud in the northwest of Sagittarius in a star-forming region of the Milky Way's Scutum-Centaurus Arm. The Lagoon Nebula is estimated to be between 4,000 and 6,000 light years from Earth. In the sky of Earth, it spans 90 by 40 arcminutes, which translates to an actual dimension of 110 by 50 light years. The nebula contains a number of Bok globules. The Lagoon Nebula also contains at its centre a structure known as the Hourglass Nebula. The Trifid Nebula is an unusual combination of an open cluster of stars, an emission nebula, reflection nebula and dark nebula."

SOUMYADEEP MUKHERJEE

Location: Río Hurtado Valley, Chile

Telescope: Telescope Live

"I'm an amateur photographer from Kolkata, India. I have been imaging objects in the sky for the last one-and-a-half years. The image shows Comet C/2017 K2 (PanSTARRS) passing by the interstellar dust in the constellation of Ophiuchus on 24 July 2022. In the second image, the comet can be seen passing by the globular cluster Messier 10, at the centre of the image. The comet made its closest approach to Earth on 14 July. The image taken on 15 July also captures another globular cluster, Messier 12."



Comet C/2017 K2 (PanSTARRS)

REVIEW

CELESTRON POWERSEEKER 127EQ

This impressive telescope's aperture and equatorial mount make it tempting to beginner astronomers

Reviewed by Russ Swan

The five-inch-diameter reflector is frequently considered an ideal choice of astronomical telescope for the serious beginner, occupying a sweet spot of good light-gathering power with reasonable economy. The Celestron PowerSeeker 127EQ is aimed firmly at this market and is the biggest and most powerful telescope in the PowerSeeker range. It comes complete with a German equatorial mount to facilitate easy tracking of objects across the night sky when properly set up and aligned and a decent aluminium tripod that provides a steady base. The standard kit includes a 20mm erecting eyepiece, a 4mm high-power eyepiece and a 3x Barlow lens.

On the face of it, this is an attractive package at an attractive price from a trusted astronomy brand, offering everything you might need to start making some worthwhile nighttime observations of the stars, planets and nebulae. However, our tests revealed that this instrument does have some shortcomings that you should consider before purchasing – specifically the optical quality of the primary mirror, its correcting elements and the supplied eyepieces and Barlow lens. The finderscope, while of good quality, is unfortunately poorly located. The accessory tray isn't as robust as it could be and the set-up instructions omit any reference to the vital task of polar alignment. There are some good components here though, and the whole package offers a useful starting point.

A conventional Newtonian reflector telescope has a parabolic primary mirror that collects light and directs it to the flat secondary mirror, which is reflected 90 degrees into the eyepiece. The design of the Celestron PowerSeeker 127EQ is subtly different. Instead of a parabolic primary, it uses a cheaper spherical mirror with additional optical elements to correct the resulting distortions. The extra components are installed downstream of the secondary mirror inside the focus tube and also serve to increase the telescope's focal length. This is how Celestron squeezes 1,000mm of focal length into a tube just 440mm long. This Bird-Jones arrangement isn't necessarily a bad thing. It results in a more compact and economical telescope, meaning the consumer gets a better handling instrument with more light-collecting power for their money. But as with any optical compromise, there will be a trade-off. Every additional optical element steals some of those precious photons collected by the mirror, giving a slightly dimmer and less sharp image. Celestron takes some steps to minimise this effect by using fully coated optics, although they're not multi-coated.

The telescope comes as standard with a 20mm erecting eyepiece and a 4mm high-power eyepiece, plus a 3x Barlow lens. The 20mm lens provides 50x magnification, or 150x used with the Barlow, while the 4mm gives 250x and a whopping 750x with the Barlow. However, the maximum usable magnification of any telescope is limited – the usual rule of thumb is 50x per inch of aperture (or 2x per mm) under ideal conditions.

TELESCOPE ADVICE

Cost: £179.99 / $206.93

From: Amazon

Optical design: Newtonian

Aperture: Five inches

Focal length: 39 inches

Lowest useful magnification: 20x

Highest useful magnification: 250x

Mount type: German equatorial

▶ The build quality is good, but the supplied accessories aren't great

◀ The hefty counterweight keeps things in place

That 4mm lens is pushing the boundaries of what any five-inch telescope can deliver, let alone one with a spherical primary mirror and additional correctors.

The PowerSeeker comes as standard with a well-engineered German equatorial mount, which is just about capable of supporting the tube. The included aluminium tripod provides a steady base and is mercifully light. The telescope comes in a substantial box weighing about 2.5 kilograms and requires a bit of assembly. The assembly proved straightforward, although you should take care to unfold the equatorial mount before attaching the tube and 3.4-kilogram counterweight. The finderscope is a lightweight plastic affair that works surprisingly well considering its small size. It's mounted relatively close to the tube though, which can be a little awkward when sighting through it.

First light for our telescope was on a distant telegraph pole, about 1.2 kilometres (0.75 miles) away, to align the finder. Using the 20mm erecting eyepiece, an impressive amount of detail could be seen on the target – even clearly identifying the species of pigeon that landed on the pole by its distinctive white collar. However, Celestron's assembly instruction leaflet doesn't mention the importance of aligning the mount with the celestial pole, and this vital detail is only found buried on page 17 of the telescope manual supplied on the CD.

There are two aspects to this: setting the correct latitude for the observing location and aligning the mount on a true north-south axis with a level base. The latitude scale on the PowerSeeker 127EQ covers a full 90-degree quadrant, meaning that you can set the correct latitude for any location on Earth. Some telescopes, including others in Celestron's range, only cover a smaller arc from 20 to 60 degrees latitude, which is fine unless you happen to be in Alaska, Sweden or the tropics.

Finding true polar alignment proved straightforward using a spirit level and magnetic compass. Our observing site happened to be close to an agonic – a line of zero magnetic variation – so aligning to magnetic north was accurate enough. Smartphone apps are available for both level and compass, although there are advantages to using old technology here as it helps preserve night vision.

Our astronomical observations proved disappointing. The standard 20mm erecting eyepiece delivered clear, sharp views of the Moon, with excellent shadow definition along the terminator. Swapping to the high-power 4mm eyepiece gave a very soft image in shades of gray, rather than black and white, which proved impossible to get into sharp focus. Even a good quality 4mm lens would be at, or even a little beyond, the maximum useful magnification for a telescope of this size. This particular lens did not perform well. Things were a little better using the 20mm with the Barlow lens. This provided 150x magnification and gave lunar images that were better than the 4mm, but still of lower quality than might be expected. A Barlow lens inevitably provides a dimmer image in exchange for its magnification boost.

Turning to the stars, the 20mm easily split the well-known double star in Ursa Major, Alcor and Mizar, showing other stars in the field reasonably well. Colour rendition was just okay, with Antares glowing orangey-red and Arcturus attempting to impersonate Mars. In both cases the colours were rather more distinct in

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CELESTRON
POWERSEEKER 127EQ

binoculars. Once again the 4mm eyepiece proved of little use and delivered only a faint smudge of colour.

Our hunt for nebulae was frustrated by imperfect seeing conditions, although with patience the luminosity of Messier 31, the Andromeda Galaxy, was detected with the 20mm. It seems a curious decision by Celestron to include these particular eyepieces in the standard kit. The 20mm is an erecting eyepiece, showing an upright image rather than the usual inverted view in astronomical telescopes. This notionally enables the PowerSeeker 127EQ to be used for terrestrial viewing, but at the expense of astronomy. Erecting eyepieces create right-side-up images by introducing additional lenses or prisms, and each new optical surface inevitably degrades the final appearance.

With the additional correcting elements in the tube to compensate for the spherical mirror and additional components in the eyepiece to erect the image, it's little wonder that performance is lower than expected. Add to this the Barlow lens, with yet more optical surfaces, and the picture worsens. Any decent telescope requires both quality optics and a steady mount, and at least here the Celestron performed reasonably. The tripod proved stable, although the flimsy plastic accessory tray wasn't so impressive. Once aligned, the equatorial mount supported the telescope adequately and the slow-motion controls proved smooth and glitch-free. All but the most delicate of adjustments resulted in a minor wobble of the telescope, which dampened in under a second. Our collimation check showed that the instrument appeared to be within tolerances as delivered, but a complete adjustment requires a special laser-sighting tool which we didn't have, so we didn't attempt this.

The instrument also comes with software, the basic edition of Starry Night. This feels rather dated now, and installation is only available on PC and Mac computers, not smartphones. That's a bit of an oversight when so many powerful apps are available in your pocket.

> “Any decent telescope requires both quality optics and a steady mount”

The Celestron PowerSeeker 127EQ will take any standard 1.25-inch eyepiece. If we were given this telescope to keep, we would ditch both standard lenses and invest in 15mm and 9mm Plössl eyepieces. We'd also drop the 3x Barlow lens for a less ambitious but more useful 2x. This set-up would provide 67, 111, 133 and 222x magnifications, making the most of the 127mm primary mirror. Celestron's single-axis motor drive unit will keep your telescope on target, automatically compensating for the turning of Earth, reducing the time spent recentring and waiting for the vibrations to dampen. This means more time doing astronomy.

This telescope is let down by the design compromises in its primary mirror and a poor selection of standard eyepieces. But it does offer a useful five-inch diameter, which even with the need for correcting optics should be able to give fantastic views of the heavens for the serious beginner. The tripod and mount are up to the job, but to make the most of this telescope additional eyepieces are needed to make the most of its potential.

The finderscope is awkwardly positioned close to the tube

FOR

- Solid tripod
- Sturdy German equatorial mount
- Good light-gathering abilities

AGAINST

- Complex optics
- Poor eyepieces
- Cheap plastics

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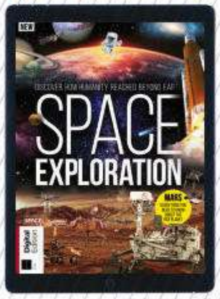
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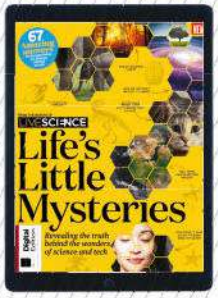
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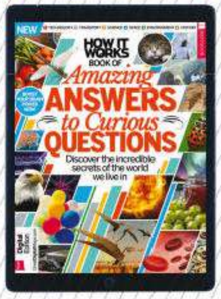
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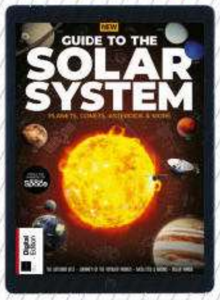
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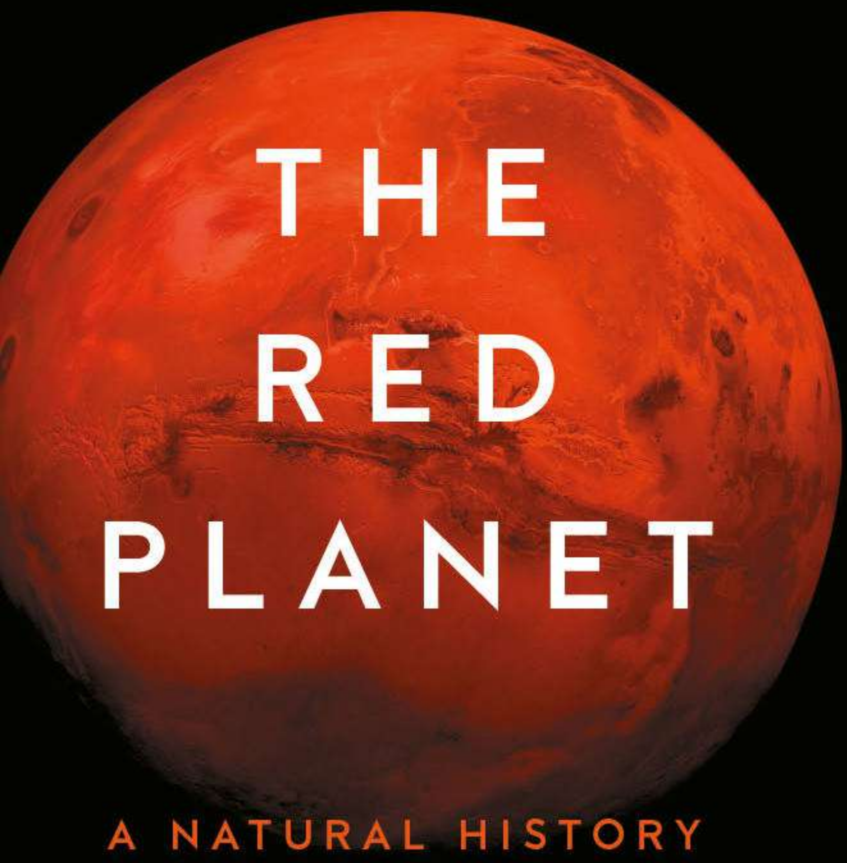
SIMON MORDEN



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IN THE SHOPS: DSLR CAMERAS

Here's our round-up of the best digital cameras on the market right now

Best overall DSLR

Nikon D850

Cost: £2,640 / $2,796.95
From: Amazon

1 The D850 is a bold step up from the D780, offering 45.7MP photos at up to 9FPS, albeit only when using a dedicated battery grip. It's not as high as some of the other cameras here, but you must bear in mind that this is 9FPS of full-resolution still images at 45.7MP – these images are enormous. If you're someone who likes to switch between capturing stills and shooting video, the D850 is worth a serious look as it also shoots in 4K ultra-high definition (UHD). What's more, this camera is extensively weather sealed, and even the battery grip is protected from dust and water. The Nikon D850 is a camera you can take anywhere, getting maximum results without fretting about the elements.

Best for action photography

Canon EOS 90D

Cost: £1,075 / $1,119
From: Amazon

2 Crop sensor DSLRs benefit from the perceived extra zoom afforded by the 1.5/1.6x effective crop. That's exactly where Canon excels with this powerhouse of a camera. The longer effective focal length and fast 10FPS burst speed are complemented by a huge 32.5MP CMOS image sensor, which was once the highest resolution of any APS-C camera. It would be nice to see 4K DCI on this camera, but 4K UHD more than keeps up with the rest of its class and is suitable for most shooters. A 220,000 RGB and IR metering sensor powers the iTR focus tracking, allowing you to keep fast-moving subjects sharp even when you're moving the camera.

Best for durability and speed

Canon 5D Mark IV

Cost: £2,759 / $2,699
From: Amazon

3 Despite being released over five years ago, the Canon EOS 5D Mark IV is still the chosen tool of many professionals. It is a must for its quality alone, as it captures 30.4MP stills and shoots in 4K DCI video for cinema-like movie quality. A large, detailed rear screen complements the bright optical viewfinder, and peripherals can be attached with USB 3.0, HDMI out and headphone outputs. It also features a microphone input, a flash connection port and WiFi and NFC technology to facilitate wireless shooting and easy image sharing.

Nikon
D7500

4

6

Canon
EOS 250D

5

> "We were pleasantly surprised when we used it for some very basic astrophotography"

Best for intermediates

Nikon D7500

Cost: £1,049 / $996.95
From: Amazon

4 Engineered for photographers who want to take their photography to the next level, the D7500 is Nikon's flagship DX crop sensor camera body. It has a large, 3.2-inch rear-tilting LCD, making it helpful when shooting at awkward angles. It's also a touchscreen that makes composing and shooting a breeze with as few clicks as possible. It's suitable for some sports and wildlife photography thanks to the 8FPS maximum burst speed, and the 20.9MP CMOS image sensor is more than enough to shoot 4K UHD video. This camera is protected from the elements as its all-around weather sealing prevents water and dust ingress.

Best beginner's camera

Canon EOS Rebel SL3

Cost: £699.99 / $749
From: Amazon

5 While there are cheaper entry-level crop sensor cameras, the tiny Canon EOS Rebel SL3 / 250D is the best of the bunch with a 24.1MP CMOS sensor and a DIGIC 8 image processor that produces vivid photos. There are only nine autofocus points across the viewfinder, but engaging the live view option on the vari-angle touchscreen improves this to 143 via camera automatic selection. This Canon also has a -4EV autofocus working range and a maximum expanded ISO sensitivity of 51,200. It's quite a handy camera in low-light conditions, especially if you pair it with a lens with built-in image stabilisation. We were pleasantly surprised when we used it for some very basic astrophotography.

Best for hybrid photographers

Nikon D780

Cost: £2,199 / $2,196.95
From: Amazon

6 Superseding the magnificent D750, the Nikon D780 builds on its predecessor's specs and features a more detailed rear screen with a huge maximum burst speed of 12FPS. This makes it an ideal DSLR for wildlife, sports and action photography. It shoots 4K UHD video with 10-bit N-log recording and 12 stops of dynamic range. A low-light master, this model can expand the ISO range to a ridiculous 204,800 and the noise-reduction algorithms are impeccable at keeping the images clean. In addition, its low-light-specific autofocus ability can drop the camera's autofocus as low as -7EV when live view is activated – especially useful for astrophotography.

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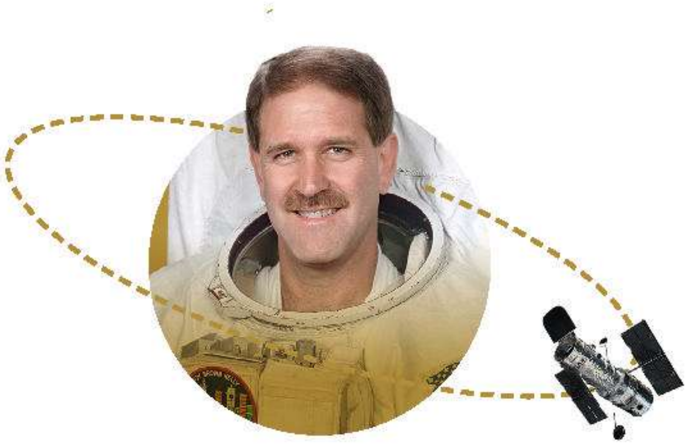
*Lens not included

HEROES OF SPACE



JOHN M. GRUNSFELD

The valiant journeys of Hubble's keeper

Born in Chicago in 1958, Grunsfeld's youth was filled with the drama and excitement of the Space Race. In 1980 he graduated from the Massachusetts Institute of Technology with a degree in physics, followed by a doctorate in astrophysics from the University of Chicago. In his spare time Grunsfeld enjoyed mountaineering, but there was a very important place he still wished to explore - space.

In March 1992 Grunsfeld was selected by NASA to become an astronaut. Determined to achieve his goal, he worked very hard, training until his first mission launched in March 1995. Aboard Space Shuttle Endeavour as a mission specialist, this 16-day mission saw Grunsfeld and his crewmates conduct a number of observations to study the far-ultraviolet spectra of astronomical objects. To achieve this they used the Astro 2 Observatory, a system of telescopes on board the Space Shuttle. Grunsfeld's leadership skills impressed NASA, and he served as flight engineer on his second flight, which was aboard Atlantis in January 1997. This was the fifth flight that docked with Mir, the Russian station where US astronauts were exchanged. They also transferred supplies and conducted a number of experiments in the laboratory. In December 1999, the experienced astronaut returned to space on board Discovery on a mission to service the Hubble Space Telescope. Grunsfeld performed two extravehicular activities (EVAs) to install new equipment on the telescope and restore it to working order.

Grunsfeld was back in space aboard Columbia when it launched in March 2002 for another Hubble servicing mission, except this time he served as payload commander. This placed him responsible for five EVAs, three of which he performed himself. Yet again Grunsfeld's work helped to expand the capabilities of the vital telescope and ensure it was in top working order. In 2009 he conducted his last flight on Atlantis, where he helped renovate and install a new camera, telescope, sensor and batteries in Hubble after its 19 years in orbit.

Grunsfeld completed a total of eight spacewalks, amassing a total of more than 58 hours of EVA time and more than 58 days spent in space. Grunsfeld retired from NASA in 2009 and became deputy director of the Space Telescope Science Institute; at the same time he took up a position as professor of physics and astronomy at Johns Hopkins University. But Grunsfeld couldn't stay away from NASA for long, and in 2012 he was appointed associate administrator for the Science Mission Directorate at NASA headquarters in Washington DC, later retiring in 2016.

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HOPE
AND
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FOR
CHILDREN

URGENT APPEAL

Russia's brutal invasion of Ukraine is not just a humanitarian crisis for the Ukrainian people; it's a child protection emergency.

Up to 100,000 children warehoused in Ukraine's vast orphanage system – a network of over 700 buildings – risk being forgotten. Left to face the dangers of war alone as staff flee. As families are torn apart or forced from their homes, many more children are at risk of being separated from the love and protection they desperately need. Worse still, they are at risk of trafficking, or being placed in overcrowded, understaffed and poorly resourced orphanages in border countries.

We must act now.

Born out of the Balkans conflict 30 years ago, we've championed the vital importance of family and community-based care of children and our teams are on the ground in Ukraine, Moldova and Romania to ensure this war does not rob children of the love and protection they need now more than ever. Across all three countries, we're directly supporting displaced families and unaccompanied children with material and emotional support. We're working closely with authorities to keep families together when they are at their most vulnerable and to fight for the safe tracking, monitoring and care for children without parental care. And we won't stop when the fighting stops.

Will you help us by donating?

With your help, we can avert a child protection crisis of epic proportions and ensure children are protected and kept in families. Never orphanages.

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Monday – Friday 9am - 5pm.

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In the event that funds raised exceed what is needed to deliver Hope and Homes for Children immediate and longer-term response to this crisis, we will use donations where the need is greatest.

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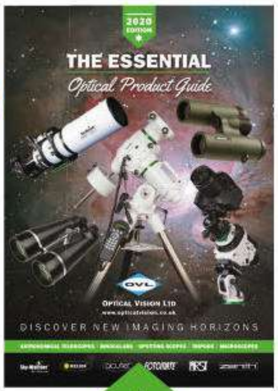

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